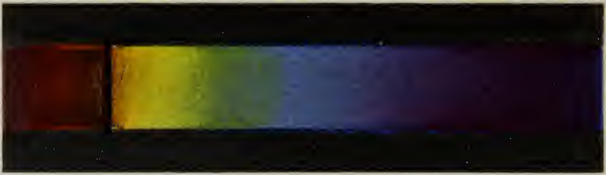
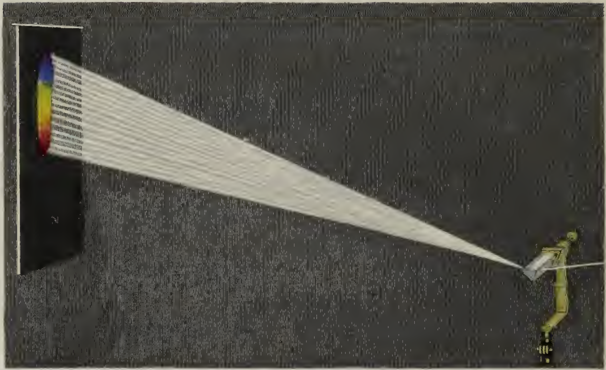
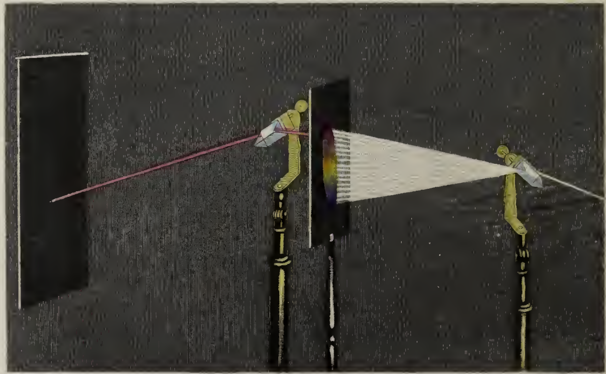
# THE WONDERS OF OPTICS.



Spectrum showing the absorptive power of Sodium vapour (Fig.6.)



Solar Spectrum (Fig. 5.)



Action of a prism on a ray of light (Fig.7)

THE

# WONDERS OF OPTICS.

BY

F. MARION.

TRANSLATED FROM THE FRENCH, AND EDITED BY

CHARLES W. QUIN, F.C.S.

*ILLUSTRATED WITH SEVENTY ENGRAVINGS ON WOOD,*

*AND A COLOURED FRONTISPIECE.*

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# PREFACE.

The present work needs but little introduction to the English public. The author, M. F. Marion, who holds a high official scientific position in Paris, is well known, especially in Europe, as a popular writer on the "Wonders of Optics," and kindred subjects. As a rule, the original text has been strictly adhered to by the Translator, but in a few instances certain anecdotes of a local character have been altered so as to be more generally applicable, or condensed to make room for the chapter on the Spectroscope, which is entirely original.

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# THE WONDERS OF OPTICS.

## PART I.

### THE PHENOMENA OF VISION.

## CHAPTER I.

### THE EYE.

THE Eye is at once the most wonderful and the most useful of all our organs of sense. It is especially by means of the eye that we gain a knowledge of the exterior world. Our other senses are far more limited in their action: thus the sense of touch only extends to objects within our reach; the sense of taste is only a delicate and exquisite modification of the sense of touch; the sense of smell can only be exercised on substances that are close to us; and the use of our ears is limited by the distance at which the loudest sound ceases to impress them. But the eye has the privilege of extending its dominion, whether for mere enjoyment or for serious instruction, far beyond the limits of this little world. Not only is it the origin of all our ideas upon every object that comes within its ken; not only does it reveal to us our own position and that of our surroundings; but, thanks to the discoveries of modern science, it is able to admire, on the one hand, a world of infinite minuteness that remained unknown to us for centuries, and, on the other, the immeasurable immensity of the starry universe.

Admirable as the eye undoubtedly is through the possession of the power of vision, it is also capable of enchanting us by its own particular beauties. Not to speak of its internal mechanism, which we shall consider very fully by and by, let us for a moment examine its outward appearance. Have you never, dear reader, been enchanted with a pair of soft and gentle eyes, or with a couple of black orbs veiled with long dark lashes, or with those wondrous eyes that rival the heavens in colour and depth, shedding on you rays of light whose mute eloquence was irresistible? If it be true that man's face is the canvas upon which the affections and desires of his mind are depicted as soon as they are formed, the eyes are unquestionably the central point of the picture, and it is in them, as in a looking-glass, that every sentiment that passes across our brain is reflected.

When the mind is undisturbed, says Buffon, all the parts of the face are in a state of repose; their proportion, unity, and general appearance indicate the pleasing harmony of our thoughts and the perfect calmness of our mind; but when we are agitated, the human face becomes a living picture, in which the passions that disturb us are depicted with equal force and delicacy, a picture in which every emotion is expressed by a stroke, every action by a letter, so to speak; in which the quickness of the impression outstrips the will, and reveals by the most sympathetic signs the image of our secret trouble.

It is more especially in the eyes, adds this great naturalist, that these signs are manifested and recognised. The eye is connected with the mind more than any other organ: it seems almost to be in contact with it and to participate in all its movements; it expresses in obedience to it the strongest passions and the most tumultuous emotions, as well as the gentlest thoughts and most delicate sentiments, and reproduces them in all their force and purity just as they have sprung into existence; it transmits them with exquisite rapidity even to the minds of others, where they once more become impressed with all their original fire, movement, and reality. The eye both receives and reflects the light of thought and the warmth of sentiment, and is at once the sense of the mind and the tongue of the intellect. Persons who are short-sighted, or who squint, have much less of this external intelligence that dwells in the eye. It is only the stronger passions that can bring the other features of the face into play, that are depicted on their physiognomy; and the effects of fine thought and delicate feeling are rendered apparent with much greater difficulty.

The elegant author of *L'Histoire Naturelle* rightly thinks that we are so accustomed only to see things from the outside, that we are hardly aware how much this exterior view of everything influences the judgment of even the gravest and most thoughtful of us. Thus we are apt to set down a man as unintellectual whose physiognomy does not particularly strike us; and we allow his clothes, and even the manner in which he wears his hair, to influence our judgment of him. Hence, our author goes on to say, not wholly without some show of reason, that a man of sense ought to look upon his clothes as part of himself, because they really are so in the eyes of others, and play an important part in the general idea that is formed of him who wears them

The vivacity or languor of the movement of the eyes forms one of the chief characteristics of facial expression, and their colour helps to render this characteristic more striking. The different colours seen in the eye are dark hazel, or black, as it is generally called, light hazel, blue, greenish grey, dark grey, and light grey. The velvety substance which gives the colour to the iris is arranged in little ramifications and specks, the former being directed towards the centre of the eye, the latter filling up the gaps between the threads. Sometimes they are both arranged in so regular a manner that instances have been known in which the irises of different eyes have appeared to be so much alike that they seemed to have been copied from the same design. These little threads and specks are held together by a very fine network.

The commonest colours seen in the eye are hazel and blue, and it mostly happens that both these colours are found in the same individual, giving rise to that peculiar greenish-grey hue that is far from being uncommon. Buffon thinks that blue and black eyes are the most beautiful, but this of course is a matter of taste. It is true that the vivacity and fire which play so important a part in giving character to the eye, are more perceptible in dark eyes than in those whose tints are lighter; black eyes, therefore, have greater force of expression, while in blue eyes there is more softness and delicacy. In the former we see a brilliant fire, which sparkles uniformly on account of the iris, which is of the same colour throughout, giving in all parts the same reflection; but a great difference may be perceived in the intensity of the light reflected from blue eyes, from the fact of the various tints of colour producing different reflections. There are some eyes that are remarkable for being almost destitute of colour, and appear to be constituted in an abnormal manner. The iris is tinted with shades of blue and grey of so light a hue that it appears quite white in some places. The shades of hazel in such eyes are so light that they are hardly distinguishable from grey and white, in spite even of the contrast of colour.

For our part, we think that the beauty of the eye consists not so much in its colour, or even in its harmony with the rest of the face, but in its expression.

There are also numerous instances of green eyes. This colour is, of course, much less frequent than blue, grey, or hazel. It often happens, too, that the two eyes vary in colour in the same individual. This defect is not confined to the human species, being shared by the horse and the cat. In most other animals the colour of the two eyes is always similar. The colour of the eye in most animals is either hazel or grey. Aristotle imagined that grey eyes were stronger than blue, that those persons whose eyes are prominent cannot see so far as others, and that brown eyes are less valuable in the dark than those of another tint; but modern investigations have failed to bear out the ancient philosopher's ideas with regard to the human eye.

Although the eye appears to move about in every direction, it has in reality only one movement, that of rotation round its centre, by means of which the eyeball rises or falls, or passes from side to side at will. In man the eyes are parallel with each other in relation to their axes; he can consequently direct them at pleasure upon the same object: but in most animals this parallelism is wanting. In some cases the eyes of animals are set almost back to back, rendering it impossible for them to see the same object with both eyes at once.

Buffon makes the remark, that after the eyes, the eyebrows contribute more strongly than any other part of the face towards giving character to the physiognomy, being, inasmuch as they differ in their nature from the other features, more apparent by contrast, and hence strike us more than any other portion of the countenance. They are, in fact, a shadow in the picture, bringing its colour and drawing into strong relief. The eyelashes also contribute their effect; when they are long and thick, they overshadow the eye, making its glance appear softer and more beautiful. The ape is the only other animal besides man that possesses two eyelashes, the rest having them only on the upper eyelid. Even in man they are more abundant in the upper eyelid than in the lower. The eyebrows have but two movements, upward and downward, governed by the muscles of the forehead. In the action of frowning we not only lower them, but move them slightly towards each other. The eyelids serve to protect the eyeball, and keep the cornea from becoming dry. The upper eyelid has the power of raising and lowering itself, the lower one being almost destitute of movement. Although the motion of the eyelids is an effort of will, there are times when it is impossible to keep them open, as for instance when we are overpowered by sleep, or when the eyes are suddenly subjected to the effects of strong light. The eyelid is a most admirable arrangement for the protection of the eye, and it is almost impossible to admire this provision of nature too much, even when we confine ourselves to an outward examination of it. It is not merely the outward mechanism and motion of the eyelids, nor the colour of the eyes, that constitutes their beauty; we have already said that the leading characteristic of the eye was *expression*. It is this expression which causes the eye to appear to speak, to fire up suddenly, to sparkle with flashes of light, to languish or conceal itself underneath its lashes, to raise itself with inspiration, or to pierce the abyss of thought, just according to the particular sentiment governing the mind at the moment. Hence it is expression that constitutes the true beauty of the eye: every one knows instances of eyes which, while at rest, would never be noticed by anybody, but which, when once animated by intense eloquence, lend to the voice of their possessor an unexpected power, which moves and transports the listener to an extent infinitely beyond that resulting from the simple spoken words.

Enough, however, has been said upon the external aspect of the human eye; we will, therefore, at once endeavour to penetrate the circle in which are contained the wonders that this little book is intended to describe. The object of these lines is not so much to describe the beauty of man's glances, nor the value of his senses, but rather to make known those illusions to which the most sagacious of all his senses is apt to fall a prey. But before entering the temple it was but right to have bestowed a little admiration upon the façade. By the way, as we are about to describe many illusory wonders, do not let us commence by deceiving ourselves with regard to our first marvel—the eye itself. A great philosopher calls the eyes the windows of the soul, and, although meant as a poetical image, the saying is not far from the truth; for the optic nerve by which we see external objects, is an extension of the nerves of the brain, whose functions and actions are an unfathomable mystery.

# CHAPTER II.

## THE STRUCTURE OF THE EYE.

Of all the senses, says an ardent admirer of nature, the sight is certainly that which furnishes the mind with the quickest and most widely-extended perceptions. It is the source of the richest treasures of the imagination, and of our ideas of the beauty, order, and unity of the world around us. How unhappy are those whom a hard fate has deprived of the sense of sight from their birth! Alas! the finest day and the darkest night differ in nothing as far as they are concerned; the light of heaven never brings joy into their hearts. The enamelled beauties of a bed of flowers, the varied plumage of the peacock, the glories of the rainbow are alike unknown to them. They cannot contemplate from the mountain height the beauties of the valley beneath; the fields golden with the harvest, the meadows smiling with verdure, and watered by winding rivers, and the habitations of man dotted about here and there over the surface of this magnificent picture. To them is unknown the sight of the mighty ocean; and the innumerable legions of the cloud army of Heaven are to them as if they did not exist. The impenetrable obscurity which surrounds them allows them neither the contemplation of what is grandest in man's outward aspect, nor even the admiration of those qualities which they themselves would hold most dear.

A strong sentiment of pity should, therefore, animate the breast of every right-thinking man, when he considers the unhappy condition of those who are born blind.

The eye infinitely surpasses in its complexity and beauty of structure all the other organs of sense, and is most unquestionably the most marvellous object that the human mind is capable of examining and understanding. Let us first examine the external parts of this wonderful organ. With what a singular system of entrenchments and defences do we find the eye provided! It is itself placed in the head at a certain depth, and surrounded on all sides by solid bone, so that it is only with the greatest difficulty that it is hurt by accident from without. The eyebrows also play their part as protection to the eye, and prevent the perspiration from entering and irritating the organ. The eyelids too are always ready to rush to the rescue, whether to protect the eye from outward attacks, or to shade it from too strong a light during sleep. The eyelashes not only add to the beauty of the eye, but they shade it from the too brilliant light of the sun, and act as advanced guards to prevent the entrance of dust or any other foreign body with which the eyes might be injured.

But its internal structure is still more admirable. The globe of the eye is almost spherical and measures nearly one inch in diameter. Fig. 1 is a view of the eyeball, showing the details of its structure; the various membranes surrounding it have been cut away in order that it may be better examined. If we commence our examination by the exterior portion of the front, we shall first find immediately beneath the eyelashes a perfectly transparent membrane (c), called the *cornea*. It is a prolongation of the hard opaque external coating of the eye, called the *sclerotic membrane*, and marked s in the figure. The cornea is sufficiently hard in its nature to present a strong resistance to any violence from without.

Immediately beneath the cornea and in contact with it is the *aqueous humour*, a thin transparent liquid occupying a small portion of the front of the eye.

Next comes the *iris*, a circular disc perforated with a round hole in the middle, and coloured with various shades of blue, brown, and grey.

The opening in the centre, which appears like a black spot when the eye is examined, is not really an object, but simply an aperture, capable of changing its size according to the quantity of light striking the eye. This change of size in the opening, or pupil, as it is popularly called, is effected by the contraction or ex-

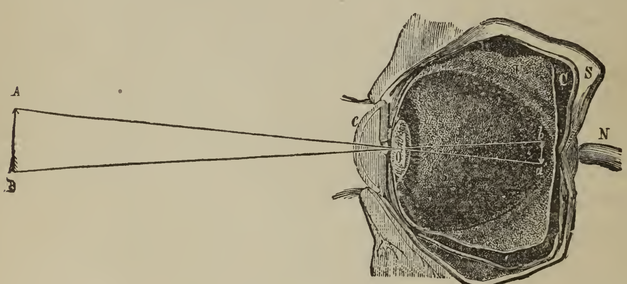


Fig. 1.—Section of the Eye.

pansion of the iris, which thus possesses the peculiar property of exactly proportioning the amount of light that enters the eye, so that there is never too much or too little. It is through the pupil that the rays of light proceeding from the various objects around us pass into the interior of the eye, and form an image upon the retina, as will be afterwards explained.

Immediately behind the pupil is O, a bi-convex lens to transmit the rays of light to the retina. It is generally called the *crystalline lens*.

From the crystalline lens to the back of the eyeball, is a space more or less globular in form, containing a gelatinous diaphanous mass somewhat resembling white of egg in appearance, and called the *vitreous humour*.

Behind the vitreous humour, and immediately opposite the pupil and lens, is the most delicate and important of all the membranes of the eye, the *retina*, which serves as a screen whereon are received the images of the objects around us. This membrane is an expansion of the optic nerve N leading from the brain, and lines the whole of the interior of the eye. The eye is also enveloped in a second membrane (C), called the *choroid*, which is impregnated with a black pigment. Round this is wrapped a third membrane, the *sclerotic* (S), which unites with the cornea in front of the eyeball.

The crystalline lens through which all the rays pass before they reach the retina, possesses the marvellous power of being able to modify its curvature in such a manner as to adapt itself to the distance of the object seen, and thus throw a distinct image on the retina. When we come to talk of the properties of lenses, we shall see that the focus of a lens differs for objects at different distances; if, therefore, the eye were not provided with some such means for altering the focus of the crystalline lens, we should only see objects distinctly at one particular point. The crystalline lens consists of infinite numbers of extremely thin transparent little plates, each of which is in itself composed of fine fibres so united together as to be capable of a small degree of compression or extension. Hence the power of the lens to alter its form according to circumstances. It is calculated that the human eye contains over five millions of the laminæ above referred to. With such wonders is the world of nature replete,—wonders that we daily and hourly pass by without examination.

It is by means of this ingenious and inimitable structure of the eye that external objects pass from the domain of the material world into that of the mind, and become accessible to every faculty of our brain. Of its own accord, and without apparently any effort of our own will, does this marvellous mechanism adapt itself to all the variations of distance and intensity of light, a power possessed by no instrument as yet constructed by the hand of man—being capable, as it is, of distinguishing instantaneously between the distance of the remotest nebulæ and that of the letters forming this page. This wonderful organ, writes Brewster, may be considered as being the sentinel that guards the passage between the world of matter and that of mind, and as the medium through which they interchange all their communications. The optic nerve perceives the objects written on the retina by the hand of nature, and conveys them to the brain in all their integrity of form and colour.

The path of the rays of light and the formation of images upon the retina are shown in the preceding figure. At first sight it will be perceived that the objects thereon depicted are in a reversed position, that is to say, when we look at a view similar to that shown in fig. 2, we should find, if we had any means of observing the positions of objects reflected on our retina, that the flock of sheep coming up the road were at the top of the eye, while the trees, the roof of the house, and the chimney were in the contrary position. Similar reversed images may be seen in dark rooms, by holding a screen before any little crack or pinhole in the door or shutter of the room. In fig. 2 the keyhole of the door is represented as playing the part of a lens. The author, in common with almost every other boy, observed this fact at a very early age, and the idea immediately struck him that it would be only necessary to fix these images to procure exact representations of natural scenery; but in making inquiries into the subject, he found that his juvenile observations had been made a little too late, photography having already gained the end he intended striving for.

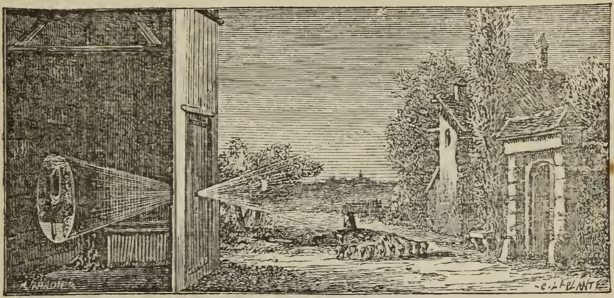

FIG. 2.—A Camera Obscura.

Seeing that the images of all objects appear on our retina upside down, the student is naturally disposed to ask how it happens that we do not see them in that position. Physiologists and natural philosophers have advanced numerous theories on the subject. Some, with Buffon, admit at once that it is by habit and education of the eye that we see objects unreversed. Others, like the great physiologist Müller, imagine that as we see everything upside down, and not a single object only, we have no points of comparison, and practically ignore the reversal. The truth, however, appears to be that it is the brain, and not the eye, that possesses the power of determining the real position of what we see. That the eye alone has no power of determining the positions of objects by itself, may be easily proved by showing a person an astronomical object, such as the moon through a telescope. Unless the observer has been already familiarized with the appearance of our satellite, he will not know whether the image he sees is reversed or not. It is the brain, therefore, and the brain only, that has the power of determining the position of objects around us, without taking into consideration the reversed picture of them that is depicted on our retina. The student who takes an interest in the structure of this important organ, would do well to procure a sheep's or bullock's eye from the butchers, and dissect it carefully with a sharp penknife and pair of scissors. The image formed on the retina may be easily seen by cutting away the sclerotic and choroid coatings at the back of the eye.

The ordinary distance of distinct vision for small objects, such as the letters of a book, is from ten to twelve inches. But possibly there do not exist two pairs of eyes in the world whose foci are the same. Even in the same individual it frequently happens that the focal length of the eyes differs considerably. In some persons the focus of the eye is so reduced that they are obliged to bring the object they are examining within six, and even four inches of their eyes, before they can see it. This defect is known ordinarily as *short sight*, and results from the too great convexity of the cornea and crystalline lens. It is corrected by wearing spectacles with concave glasses. Others again, on the contrary, place the book or object they are looking at, at a greater distance from the eye than that named. Such people are called long-sighted, and the defect results from the too great flatness of the cornea and the crystalline lens. The fault is of course corrected by the use of spectacles containing convex lenses.

Long-sightedness is generally the result of old age, and it may be taken as a fact that the older we grow the flatter becomes the crystalline lens. Hence short-sighted people have been known to recover their sight perfectly as they advance in years through the natural process of the flattening of the crystalline lens. These matters, however, will be more fully treated of when we begin to speak of the properties of lenses of different forms and curvatures

## CHAPTER III.

### THE ERRORS OF THE EYE.

It is with our own organization that we shall commence our task of exposing the illusions that we shall meet with during our optical experiments,—in fact with that wonderful and important organ of our body that we are apt to look upon as sure and infallible, but which we shall find is deceiving us constantly, and hourly proving the fallacy of the popular saying, that "every one must believe his own eyes." In ancient times there existed a school of sceptics who doubted everything beginning with Pyrrho, the great theorist, and ending with the follower of his school who doubted the existence of muscular force even after he had received a sound box on the ear from an opponent of his system of philosophy. If any of our readers were to become followers of Pyrrho, they might easily do so when considering the numberless illusions we shall describe to them, if they did not remember that if our senses are subject to error, we have a brain to set them right: our mind, if logical and well regulated, soon discovers errors of observation, and speedily places our judgment on the most solid basis. We shall find endless instances of this throughout our little book. If we are dazzled with illusions from time to time we shall as often recover ourselves; and no matter how beautiful or interesting these deceptions may appear, we shall speedily be able to convince ourselves that they are unreal. In this chapter we shall only speak of those errors of the eye of which we have actually lost all cognizance, so effectually has our judgment succeeded in counteracting their influence.

We all know that the first thing a child does with its eyes, even when it is only five or six weeks old, is to turn them towards the most brilliant object within its reach. Instinctively and without being aware of it, the child's eye seems to seek the light. The whole of nature, from the lowest plant to the baby in the cradle, appears more or less endowed with this instinct of turning towards the light.

From the time that children begin to distinguish objects, their eyes are liable to be affected by two causes of error. Before being able to judge of the position of things surrounding them, they see everything upside down; they consequently acquire a false impression of the position of objects. The next cause of error that is likely to mislead them is the fact of their seeing everything double, a separate image of everything being formed on each eye; and it can only be by the experience gained through the sense of touch that they can acquire the knowledge necessary to rectify these errors, and see those objects single which appear to them double. This error of sight, as well as the first one, is set right so easily in the end, that although in reality we see everything double and upside down, we imagine that we see them single, and in their proper positions, a state of things brought about entirely through another sense exercising its power over our judgment; and it is hardly too much to say that, if that sense were deprived of the power of feeling, our eyes would deceive us, not only as to the number, but the position of the objects within our view.

It is very easy to convince ourselves that we really see objects double, although we imagine them to be only single. We have only to look at the same object first with the right eye, and we shall see it directly against some portion of the wall of the room in which we are sitting; then looking at it with the left eye, we shall see that it covers a different part of the wall. This experiment is easily tried, and is very convincing. Thus we see that an image is formed on both eyes, and we consequently see the object, whatever it may be, repeated twice. By degrees, however, the eyes gain the power of converging their axes on objects at different distances, so that they fall on similar portions of each retina, and so convey a single impression to the brain. Thus, for instance, if we look at a pencil held up at arm's length, and then, without changing the position of the eyeball, look at some distant object, we shall see it double. Let us, however, converge the eyes upon it, and the two images unite. Reverse the experiment by now looking at the pencil without converging the eyes upon it, and we shall see that object double in its turn. The same thing happens if we push aside one of the eyes with the finger while looking at any object. During severe illness it often happens that the patient from extreme weakness loses the power of convergence, and consequently sees every thing double, and we continually see children's faces wearing a most distressing appearance through having temporarily lost the power of moving the muscles of the eye. It is a common expression to use in speaking of drunken people, that they see double, but the saying, unlike many others, is no metaphor; when a man gets drunk he loses his power over the muscles of his eye, just as he does over those that sustain his body, and the instinctive closing of one eyelid, in order that he may see objects single, is an effort of his weakened judgment to set things right once more.

While on this subject we may mention the experiment made by the famous English surgeon Cheselden upon a boy who was born blind, and upon whom he operated successfully.

This boy, who was thirteen years old at the time that Cheselden restored to him the sense of sight, was not born absolutely blind, his affliction having been caused by a cataract or film spread over the eyeball, which allowed him to distinguish night from day, or black from white or scarlet when placed in a very good light, although he was unable to perceive the form of things around him. At first Cheselden operated on a single eye, perfectly restoring its power; but so little idea of distance did the new sense convey to the boy's mind that for a long time he imagined that everything touched his eyeball, just as those he felt touched his skin, and it was only by the sense of touch that he could persuade himself of the fallacy of his supposition. At first he had no perception of form whatever, and could only recognize objects he had already been familiar with after he had felt them all over. He was a long time, for instance, before he could distinguish between the dog and the cat without touching them, and was greatly surprised to find that the persons and things he had liked best when blind were not always the pleasantest to his newly acquired sense. His ideas of size, too, were all at fault, and he could not, for a long time, be made to understand how his father's picture could be got into the back of his mother's watch; even after he had possessed his sight for a comparatively long time, he could still only recognise people he had known during his blindness by touching their faces. Whenever he saw a new object he looked at it attentively for some time, in order, as it were, to learn its form by heart; but his memory was at first so overtaxed that he continually forgot his visual impressions, and mistook one thing for another. He was more than two months before he could appreciate form as depicted in a painting or drawing, having hitherto learned to consider pictures as flat objects. When, however, he began to understand the power of light and shade in producing the representations of solid objects, he was often extremely surprised to find the surface on which they were depicted quite flat when he touched it. The same thing frequently happens to ourselves, when looking at the photographs of bas-reliefs for instance. If these objects be well photographed, with the proper arrangement of light and shade, the illusion is so complete that the finger involuntarily touches the paper to feel if the surface is not really raised. In the Bourse at Paris there are some figures painted to represent bas-reliefs in so wonderful a manner, that numberless bets have been made, lost and won, over them. When feeling such representations of solid objects, the boy would often ask those around him which of his senses was deceiving him, his sight or his touch.

At first he saw everything of an enormous size, but as he saw things larger than those around him, he found the latter diminish. He also imagined that there was nothing beyond the room he was in, and could not be brought to comprehend how the house could be larger. When the sight of the second eye was restored to him a year afterwards, he at first saw every object of an enormous size, just as in the case of the first eye; but as he had now the perfectly educated organ to help him as well as his sense of touch, he soon began to see things under their natural appearances.

While he was in ignorance of what sight really meant, he was not particularly anxious to undergo the operation, saying that he did not think it possible to derive more pleasure from things that he liked than he did while he was blind. But now that his sight was restored he found every fresh object a new pleasure. When first he was shown the landscape from the top of a high hill, he was so delighted that he exclaimed that he had found another sense. When his second eye was operated upon, he saw things apparently twice as large with both eyes as with the one already restored to him. Even at first he seemed to have no difficulty in converging the eyes on any object.

These extracts from the history of Cheselden's patient show us how utterly incapable the eye must be of rightly understanding the number, position, size, and form of objects without frequently correcting our impressions by the aid of the sense of touch.

## CHAPTER IV.

### OPTICAL ILLUSIONS.

Besides the errors of sight already spoken of, there are other illusions, which are either common to all persons or confined to certain individuals, the knowledge of which will serve as a fitting prelude to the descriptions of those which are artificial.

The following defect, for instance, is one which is little known, but notwithstanding our ignorance of its existence it is nevertheless true that we all suffer from it. There is in every one's eye a blind spot, totally incapable of experiencing the effects of the rays of light when they impinge upon it. For objects situated opposite to this particular spot we are as completely blind as if we had no eyes at all. To convince yourself of the truth of this assertion it is only necessary to try the following simple experiment.

Place upon a piece of white paper two small wafers, or two blots of ink about an inch and a half apart. Take the sheet in your right hand, and hold it up parallel to the lines of the eyes; shut the *left* eye, and fix the *right* eye on the centre of the *left* wafer or ink-spot. Move the sheet of paper steadily towards the eye, until it is about two inches and a half or three inches' distance from it, and you will find that in a certain position the *other* wafer or ink-spot will disappear, although it is evidently still in the field of view. Having discovered this point which differs for different eyes, you will find that if you diminish or increase the distance of the paper you will once more see the missing object. The same thing happens if you move the eye from the centre of the wafer. The same experiment may be repeated with the left eye with a precisely similar result.

It has been found by experiment that this particular blind space exists exactly over the base of the optic nerve, at the spot where it joins the eye. (Fig. 1.) Thus we see that the nerve which actually conveys the impression of sight to the brain is in itself incapable of being excited by light. In such cases as these Nature seems to laugh at us, and escapes from our grasp just as we are most confident in our power of wresting her secrets from her; indeed we may compare her to a wise and good-natured mother, who, though always amiable and willing to instruct those about her, sometimes smiles when her children fancy they are as learned as she is.

If we do not perceive the constant recurrence of the phenomenon just menti ned, it is because when both eyes are open the object whose image falls on the blind spot in one eye is seen by the other, the insensible portions of each eye being on opposite sides. Not only this: the spot being always situated on the outer and indistinct portion of the image reflected on the retina, we do not take notice of it; for as every one has no doubt observed, it is only the small portion of the object we are looking at exactly opposite the centre of the eye that is perfectly distinct and clear, all the rest being confused in its details, although quite visible.

Again, we may account for our not noticing it by the fact of our seeing clearly only those things which specially attract our attention—a fact first noticed by Mariotte. We see only what we wish to see with our physical eyes, as well as those of our mind. If our attention is attracted by a particular portion of a landscape, we see only that, and nothing else. If it is fixed on some subject that we are contemplating inwardly, we see nothing at all, although our eyes may not only be wide open, but absolutely fixed on some particular object. For instance, suppose a sportsman is out in the fields preceded by his dogs, Bran and Ponto. If he follows the movements of Bran with attention, he becomes the only object animate or inanimate, that depicts itself on his retina. Ponto may jump and caper in vain: he is lost to his master's eye as much as if he were not there at all; his mind is entirely fixed on the beauty of Bran's coat, on the fit of his collar, or fifty other things, and he sees nothing else. But let the sportsman begin to think of the number of birds he shot yesterday, or how he will find time to get up to the grouse in Scotland, or of that fine stag he missed when he was last amongst the heather, and dogs, cover, and landscape will fade from his sight as effectually as if he had been struck with blindness. Let him, however, strike his foot against a stump, or let the dogs suddenly begin to point, and he instantly receives back his sight, which but a few moments before he had lost to all intents and purposes.

The phenomena of *ocular spectra* and *complementary colours* experienced by every one forms a curious chapter in the history of those illusions which take their origin in the eye itself. Every one has noticed that after looking fixedly at a bright light or a striking colour for a few moments, the eye preserves an impression of the object for a certain time. A very light window looked at intently for several seconds will leave the impression of its cross-bars on the retina for several minutes, the colour of the image changing at every movement of the eye. The same effect may be observed when looking at the setting sun, or a flaring gas light. If the light at which we look is coloured, we shall see the complementary colour in the impression left on the retina. Sir David Brewster was one of the first to notice and experiment upon these very interesting facts.

If we cut out any simple figure, a small cross for instance, in scarlet paper, place it upon a white background and look at it fixe lly for a minute or two, we shall find that its tint will gradually become duller. If we now suddenly look at a piece of white paper, we shall see the cross depicted upon it in green, which is the complementary colour to red. It should be explained, that the complementary of any colour is that which is necessary to make white light. Thus, blue, yellow, and red (as we shall find out when we come to speak of the prismatic spectrum), mixed in certain proportions, form white light; consequently the complementary of orange, which is composed of red and yellow, will be blue; of green, which is yellow and blue, red; of purple, which is blue and red, yellow, and *vice versâ*. The complementary of black is white, and of white, black as a rule; but if the white object be very brilliant, the black spectrum will speedily become coloured. The impression left by the setting sun is of this character. At first, while the eye is open, the image is black, then brownish red, with a light blue border; but if the eye be shut suddenly, it becomes green, with a red border, the brilliancy of colour being apparently in proportion to the strength of the impression. These spectra may be perceived for a long time, if the eye is gently rubbed with the finger now and then. Some eyes are more impressionable in this respect than others, and Beyle gives an instance of an individual who saw the spectrum of the sun for years, whenever he looked at a bright object. A modern instance of this occurred lately to an amateur astronomer who was looking at an eclipse of the sun. He unfortunately used a glass that was not sufficiently smoked, and the image of the sun's disc, with the black space caused by the intervening moon, remained on his retina for months after. This gentleman's case afforded an instance of the necessity of attention in order to see any object, for after the first few days he only became sensible of his unfortunate mishap when his attention was called to it by some accidental circumstance. These facts were so inexplicable to Locke, that he consulted Newton on the subject, and was surprised to learn that the great philosopher himself had suffered for several months from a sun-spectrum in the eye.

Without affirming that optical illusions are the cause of all the supposed supernatural appearances of which we have heard so much, there is no doubt that in many instances the eye plays an important part in deluding the brain. The following example, also cited by Beyle, will show this clearly. A horseman dressed in black, and riding a white horse, was trotting along a portion of the road, which through a sudden break in the clouds was brilliantly illuminated by the rays of the sun. The black figure of the man was projected against a white cloud, and the horse appeared doubly brilliant from being seen against the dark-coloured road. A person who was greatly interested in the arrival of the horseman was watching them with great attention, when suddenly the horse and his rider disappeared behind a wood. An instant after the observer was terrified at seeing a *white* cavalier on a *black* horse projected on a white cloud at which he was accidentally looking. It may be readily imagined that such an occurrence, followed up by a succession of unusual events,—such as illness, death, or any other series of misfortunes,—might even in the present day add a chapter to the history of the marvellous.

To the illusions to which, like the preceding, we are all subject, may be added those resulting from some abnormal conformation, or some disease of the eye, in those who labour under them. An example of this occurs in the case of double or triple vision, many remarkable instances of which are mentioned by Müller, the celebrated physiologist.

Although, as before explained, the image of an object is depicted at the same time on both our eyes, still we only see one impression, in consequence of the two images being carried to the brain from corresponding portions of the retina. If this relation be disturbed by any cause, or if the eyes are not converged exactly upon the same point, a double image is the result. The first of these facts may be proved by looking at the moon, for instance, with the left eye shut; on suddenly opening it, two images will be seen for an instant. The second is instantly proved by pushing either of the eyes aside with the finger, when looking at any object.

It is necessary, however, to distinguish between these effects and true double vision, as well as a certain defect which exists in the eyes of many people, consisting in the apparent multiplication of distant objects by the same eye. In these cases, there is a superposition of images upon the retina, each having its proper bounds. With the majority of individuals afflicted in this way, it only happens when they look at a very distant object, the moon or stars for instance. There are many, however, who suffer from it in the case of everything they look at, whether far or near. Stephenson, who was affected with it, made it the subject of many interesting experiments. When he looked at a clear mark on a white ground, and gradually walked away from it, not only did the image become indistinct, but it seemed to unfold itself into several, independently of many others much more indistinct, more especially two situated on each side, whose distance increased the farther he walked away. As these latter images became more and more separated, they also became more confused. The image seen by the right eye was a little higher than that seen by the left. Griffin states, that after having used the telescope for any length of time, the eye that he kept shut always saw objects triple and double for some hours afterwards. These phenomena are possibly connected in some way with the disposition of the plates and fibres of which the crystalline lens of the eye is composed.

Semi-vision, or *hemiopia* as it is called, is much more rare and more difficult to explain than the phenomena of double vision; and consists in the power of being able to see only the right or left half of the object looked at, the separation being vertical when the eyes of the observer are in the same horizontal line. Thus, in looking at the word NEWTON, the person so afflicted would only see either the letters NEW or TON according to which half of the eyes were defective.

Wollaston was afflicted with hemiopia on two different occasions; the first time after violent exercise, during two or three hours, when he could see distinctly only the left-hand halves of the objects he was looking at. Both eyes were similarly affected, and the phenomenon only lasted about a quarter of an hour. Twenty years afterwards he suffered again from the same accident, but on this occasion in the contrary manner; that is to say, he only saw the right halves of the objects he was looking at—to use his own words, he could only see the right half of every friend he met. At certain distances from the eye, one of two persons would become invisible, and by simply changing his own position or that of the persons he was near, he could make one or other of them, or indeed both, disappear at will. It must be acknowledged that similar tricks of Dame Nature, due to an unconscious insensibility of the eye, are most singular, and at first sight appear to have a supernatural origin.

Bartholin mentions the case of a hysterical woman who was afflicted with hemiopia horizontally, and saw all natural objects cut in two, the lower halves being invisible. In this instance it was only the left eye that was defective.

Another interesting example of optical illusion is the luminous sensation produced internally when the eye, or the neighbouring parts, are struck or stimulated by friction or electricity. These appearances are experienced even by those who have lost their sight. Müller states that a case was submitted to a legal tribunal to decide whether the luminous sensations which are perceptible when we rub our eyes are really light. The matter in dispute was whether a man who was attacked by robbers in the dark, could see and recognise them by means of the light produced in his eyes by a violent blow on the head; but he does not tell us how the question was decided. With regard to internal causes, Humboldt tells us that a man whose eye had been extirpated, was sensible of luminous appearances whenever he was galvanized. Lincke states that a man whose eye had been removed by a surgical operation, saw next day all kinds of luminous phenomena, which tormented him cruelly with the idea that after all his eye had been saved. When he shut the perfect eye, he fancied he saw with the missing eye circles of fire, persons dancing, and similar appearances for several days. These facts are analogous to those told of persons who have had their legs and arms amputated, but who, notwithstanding, apparently feel pain in their lost limbs.

## CHAPTER V.

### THE APPRECIATION OF COLOUR.

Most people understand each other sufficiently to agree in their ideas about various colours. Thus every one agrees in saying that poppies are red, that the sky is blue, and the leaves green; but if any one were to assert that the sky was red, that the leaves were blue, and poppies green, who could possibly contradict him?

This statement may appear a paradox, and an absurdity to many of our readers, but it is really a problem that has engaged the attention of many of our greatest philosophers. Who can prove that what I see as yellow may not appear blue to you, or that what you see red is not green to me? You would possibly explain the doubt by saying that because we both agree in calling a buttercup yellow, that we see the same colour. I call a buttercup yellow, because I have learnt since my childhood to give this name to the particular sensation I experience when I look at one of these flowers; but that is no proof that the sensation I feel is similar to that felt by everybody else, and it is not merely possible, but probable, that our personal sensations of colour are essentially different, although the arbitrary words we use to designate them are the same.

It may be remarked in parenthesis, that colour is not an entity, but is simply the effect of certain properties of surface or interior structure possessed by every substance with which we are acquainted. The old saying, that "all cats are black in the dark," is really a profound philosophical truth, which is not only true of cats but of the reddest rose that ever grew in a garden, the bluest violet that ever was plucked, the prettiest girl that ever was kissed under the mistletoe. It is a sad thing to think of, that when we put the candle out, and step into bed, we become blacker than the blackest negro that was ever emancipated. But without light there can be no colour, for there is no material, so to speak, from which to manufacture it. White light, as we have said before, is made up of red, blue, and yellow, and it is by the absorption of one or all of these that all tints are formed. The surface of a poppy leaf has the power of absorbing all the blue and a little of the yellow, reflecting the whole of the red and the remainder of the yellow, the mixture of the two forming scarlet. The surface of a marigold acts differently; all the blue is absorbed, as in the case of the poppy, and a good deal of the red with it, leaving just a little to brighten up the yellow which is reflected with it. Some substances, white marble for instance, have no power of splitting the light into colours, absorbing some and reflecting others, but reflect the whole of it in its integrity. Others again, like black velvet, absorb nearly the whole, just reflecting sufficient to enable us to see its surface.

We began this chapter by speculating on the probability of our seeing different colours to our neighbours, and we shall now proceed to show that our speculations in that direction are not so absurd as they appear to be at first sight.

The phenomenon of colour blindness, or the insensibility of the eye to certain colours, has been for many years past a puzzle both to the physiologist and the philosopher. Perhaps the most remarkable case of the sort is that mentioned first by Huddart, and quoted by Sir David Brewster, of a shoemaker named Harris, living at Maryport, in Cumberland, who was utterly incapable of distinguishing any colour at all, and saw everything white, grey or black. The first time that Harris noticed this defect, was when he was about four years old; having found the stocking of a playmate in the street, he returned it to him at his cottage, and noticed that every one said it was a red stocking, but he could not understand why they should call this particular stocking red, as it seemed to him to be like every other. This circumstance remained in his mind, and a few more similar observations confirmed his suspicions that he had some defect of sight that prevented him from seeing as others did. He also observed that other children pretended to distinguish cherries from their leaves by what they called their colour, whilst he could see no difference between them, except those of shape and size. He also noticed that by means of the difference of colour, others could distinguish cherries on a tree at a much greater distance than he could; whilst he, on the contrary, could see other things at greater distances than his companions. Harris had two brothers, whose eyes were similarly defective; one of these, that Huddart examined, mistook green for yellow constantly, and orange for light green.

In the *Philosophical Transactions* Scott describes a similar defect in his own powers of vision. He states that he was unable to distinguish green, and that the colours known as crimson and pale blue presented no difference of hue. He further confesses his inability to see any difference between bright green and bright red, although he could distinguish between red and yellow, dark blue, and almost every shade of blue, except sky-blue. He goes on to relate how he married his daughter to a worthy young man of his acquaintance, and that the day before the wedding the bridegroom came to his house in a full suit of black, as he thought. He was greatly displeased to see him appear in mourning on such an occasion, and took an opportunity to remonstrate with him on the subject. But what was his surprise to hear his daughter exclaim, in loud tones of counter remonstrance, that she had rarely seen her lover in a coat of such a pretty colour, and that her father's eyes must deceive him on this as on many other occasions. Scott's father, his maternal uncle, one of his sisters, and two of his sons had the same defect of sight. Dr. Mitchell mentions the case of a naval officer who for his ordinary uniform chose a blue coat and waistcoat and red trousers, fully believing that they were all of the same colour. A tailor of Plymouth, also mentioned by Dr. Mitchell, mended a black silk waistcoat with a piece of crimson, and another put a red cloth collar to a blue coat. Several celebrated men have suffered from colour-blindness. Amongst them may be mentioned Dugald Stewart, the great philosophical writer; John Dalton, the originator of the atomic theory; and Troughton, the philosophical instrument maker. Dugald Stewart first discovered the defect on hearing a member of his family admire the contrast of colour between the leaves and fruit of a Siberian crab-tree, while he could see no difference between them, except in point of form and size. John Dalton could not distinguish blue from crimson, and he could only see two colours, blue and yellow, in the prismatic spectrum. Troughton could see no difference between dark crimson, bright orange, and yellow—in fact, he could only distinguish blue from yellow.

In an article on this subject, published in the *Magasin Pittoresque* for 1846, a Swiss physician gives some interesting examples, which are worth repeating. In the solar spectrum obtained by passing a ray of light through a triangular prism, and which is composed of the following colours,—red, orange, yellow, green, blue, indigo, and violet,—Dalton could only see yellow, blue, and violet. Rose-colour by day appeared to him a pale blue, but at night it seemed to take an orange hue. By day crimson seemed to be dirty blue, and red cloth dark blue. Dr. Whewell having asked him one day to describe the colour of the doctor's scarlet gown, Dalton pointed to the trees around them, and declared he could distinguish no difference in their colour; and one day having dropped a stick of red sealing-wax in the grass, he had the greatest difficulty in finding it again. Since Dalton's time over five hundred distinctly marked instances of this imperfection have been noticed, and Professor Prévost, of Geneva, has named it *Daltonism*, an extremely unphilosophical piece of pathological nomenclature, which has unfortunately received the sanction of too many great physiologists to be abolished. Blindness might just as well be called *Homerism* or *Miltonism.*

Colour-blindness is much more frequent than is generally supposed, for those who are afflicted with it are mostly ignorant of the defect, and frequently practise trades or professions in which perfect sensibility to the different hues of colour is quite indispensable. An instance of this occurred some time since in the case of an engine-driver, who allowed his engine to run into a luggage train, through not noticing the red danger signal. At his examination it was proved that he was colour-blind, and could not distinguish red from green. Partial colour-blindness is, no doubt, the cause of the frequent disputes that we hear about the tints of certain objects; to say nothing of the glaring instances of bad taste in the arrangement of colour that are now-a-days so common. Out of forty boys at a school at Berlin who were examined by Leebech, he found five who were quite confused in their notions of colour, and could not distinguish between ordinary shades of the same hue. This affliction is in many cases hereditary, descending from father to son. It is singular that instances of colour-blindness are much more common amongst men than amongst women, for out of over five hundred cases there were only four in which females were the sufferers. It seems also that persons with grey eyes are more frequently colour-blind than those whose eyes are blue or brown. To the list of great men who were colour-blind, we must not forget to add the celebrated Italian historian, Sismondi.

Physiologists consider that there are two kinds of colour-blindness,—one where only two colours are seen, the other where more than two are perceptible. Daubeny Turberville, an oculist of Salisbury, mentions a case of the former, in which a young girl, like the Maryport shoemaker mentioned by Brewster, could only distinguish between black and white, everything between the two being of different shades of grey. This girl, singularly enough, could see to read in twilight a quarter of an hour after her companions. This sharpness of sight appears to be not at all uncommon amongst those who are colour-blind. Spurzheim mentions the case of a whole family who were afflicted in the same way as Turberville's patient. All the male members of Troughton's family were equally incapable of distinguishing any colours but blue and yellow.

The cases of colour-blindness where more than two colours are distinguishable, are much more common. Goethe, the great German poet, who dabbled a great deal in optics, knew two young men who, although they possessed powerful sight, and could distinguish between white, black, grey, yellow, and orange, were at a loss when the shades between dark red and rose colour were in question. A piece of dried carmine appeared bright red to them, and a faint carmine hue on a white shell, and a rose-leaf, light blue; the leaves of trees and grass appeared yellow, and they confounded rose-colour, blue, and violet together. Goethe supposed them to be incapable of perceiving blue and its several hues, and called their defect by a high sounding Greek name, *akyanoblepsy*, or blue-blindness. Péclet mentions two other persons, also brothers, who likewise were incapable of distinguishing between blue, violet, and rose-colour. Like Professor Whewell, they confounded the dull scarlet of the trousers of the French infantry with the leaves of the trees. Yellow appeared to them more brilliant than any other colour. Doctor Sommer and his brother could not distinguish between red and its derivatives and other colours; they could only distinguish between yellow, blue, white, and black. Doctor Nicholl mentions a child that could only see red, yellow, and blue, in the spectrum. It could distinguish green, but called it brown when it was dark, and pink when it was pale. The same physiologist knew a man who called red green, and brown dark green. A young lady who was an amateur artist, could not perceive a piece of scarlet cloth hanging on a hedge that was close to her, although others could see it plainly half a mile off. One day she gathered, as a great curiosity, a lichen which she supposed to be of a bright scarlet hue, but which was in reality of a beautiful green. Another time she could see no difference between carmine and prussian blue. A gardener living at Clydesdale, who began life as a weaver, was compelled to give up his first trade because in daylight he confounded all light colours; yellow and its varieties he could distinguish perfectly, but he was incapable of seeing any difference between red, blue, pink, brown, and white. Another man, who was a silk-weaver, had to change his trade, because he could not distinguish between red, pink, and sky blue. A Genevese artist whom circumstances compelled to paint a portrait by candle-light, used yellow for pink in laying on his flesh tints, with a pleasing result that may be readily imagined. In fact, the instances of colour-blindness mentioned by physiological writers are almost innumerable, and I should only weary my readers if I related all the authentic cases of this singular affliction. One instance, however, which was very carefully observed by Wartmann, a distinguished German oculist, merits our attention. The afflicted person, whom Wartmann speaks of as D., was thirty-three years old. Those of his brothers and sisters whose hair was fair suffered from the same infirmity, but those whose hair was dark were exempt from it. Like so many others who are colour-blind, he could not distinguish between cherries and their leaves, and confounded a sea-green piece of paper with a scarlet ribbon placed near it. A rose of the ordinary hue appeared greenish-blue. Being anxious to see if reflected, refracted, and polarized light exercised a different action on his retina, Wartmann tried him first with the prismatic spectrum, but he could only distinguish four colours,—blue, green, yellow, and red. He could distinguish perfectly the peculiar black lines seen crossing the spectrum in certain places, and known by the name of Fraunhofer's lines. He then placed in his hands thirty-seven pieces of differently coloured glass, but he could only distinguish four varieties. The colours produced by polarized light seemed to give the patient quite as much trouble as those produced in the ordinary way. Chocolate brown appeared reddish brown; purple, dark blue; and violet, a dirty blue. When colours were illuminated by sunlight, they seemed to him to be redder than usual, even green and blue appearing red.

In considering cases of colour-blindness, it is very difficult not to be misled into using wrong terms, as applied to colour, for we have no possible means of knowing what colour it is that is really seen by the patient.

Thus, for instance, Dr. Whewell could not distinguish between red and green. But what colour did he really see? Did he see the leaves and cherries both red or both green, or was it some colour between the two that was impressed upon his retina? Again, great care must be exercised in placing implicit reliance on the statement of persons who are colour-blind, for we must recollect that their only means of conveying the results of what they experience is by the use of an organ that is confessedly defective, and which is quite likely to deceive them, and us too, without their being parties to the deception.

The cause of colour-blindness is completely unknown; philosophers and physiologists are still in the realms of hypothesis concerning this peculiar optical defect. As yet, the most careful observation has failed to detect any difference between the eyes of those who are colour-blind, and the eyes of ordinary persons, that could in any way account for this singular affection of the sense of sight.

# CHAPTER VI.

## ILLUSIONS CAUSED BY LIGHT ITSELF.

WHEN playing about the Christmas fire, children frequently amuse themselves by whirling round and round a piece of wood, one end of which they have previously lighted and blown out. In proportion as the movement becomes more rapid, the path of the red-hot end becomes more and more connected, until at last a burning ring is formed, in every part of which the shining charcoal appears to be at the same time. The only way of accounting for this illusion is by supposing that the image formed by the burning stick upon the retina remains there for an appreciable period, the impression made by it at one part of its journey remaining until it returns to its former position. The power possessed by the retina of retaining impressions explains a large number of illusions of the same kind. The chord of a musical instrument, for instance, when struck, appears to occupy a longer space during the time it vibrates, than when it is at rest. A rapidly revolving wheel appears almost solid on account of the combined images of the spokes seeming to unite into one homogeneous mass.

The persistence of luminous impressions upon the retina has given rise to the invention of a number of well-known optical toys, amongst which may be mentioned the *phenakistiscope*, the *thaumatrope*, the *phantascope*, and many others.

The phenakistiscope may be described (figs. 3 and 4) as consisting of an iron pin *a b* turning easily on its axis, and passing through two holes in a brass rod *t g*, bent twice at right angles. Attached to one end of the pin is a disc of card-board, divided into several equal sectors, and pierced near its circumference with as many similar sized rectangular holes (fig. 4) In each sector the same scene is represented, with this difference, that the movements of the objects are so arranged as to be progressive from one extreme to the other. The disc being fastened to the pin *a b* (fig. 3) by the screw *v*, with the figures facing outwards towards *a*, the whole apparatus is held before a looking-glass by the handle *m*. If the disc be now rotated by the button *b*, and the eye placed opposite one of the square holes in the card, the figures on the disc will appear to move more or less quickly according to the rate at which it is rotated. The three bricklayers in fig. 4 will be seen to pass their bricks from one to the other with perfect regularity if the drawing has been made carefully. Numberless other designs may be made for this little instrument, such as a windmill in full sail, a man working a pump, a conjurer swallowing knives—in fact, any scene with objects in motion may be drawn, and will cause infinite amusement for the long winter evenings.

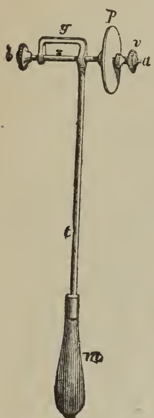


FIG. 3.—The Phenakistiscope.

The time during which the impression of any object remains upon the retina appears to be in direct proportion to its brilliancy. For a burning coal it is stated to be about the tenth of a second; consequently, if the stick mentioned at the beginning of the chapter is rotated ten times in a second, a continuous luminous ring will appear to be formed. That the time necessary for producing a distinct impression varies with the brilliancy of the object, may be readily guessed from

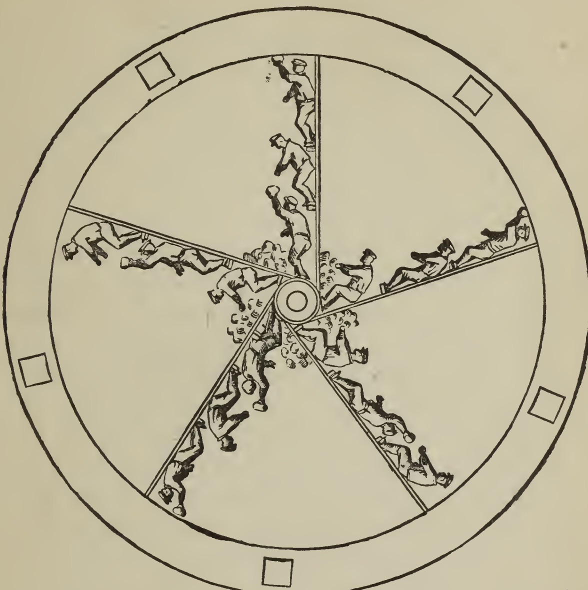

FIG. 4.—Disc of the Phenakistiscope.

the fact that an electric spark is perfectly visible, although its duration can hardly be measured, while a cannon-ball in flight is only perceptible to the practised eye of the artilleryman, owing to its reflecting only a small quantity of very diffused light.

The second instrument, the thaumatrope, is constructed on the same principle. It consists of a certain number of circular discs of card three or four inches across, which are capable of being turned on their axes with great rapidity by means of the finger and thumb and a couple of silk threads fixed at opposite sides of their circumference. On each of these discs a design is painted, one half appearing on one side, and the other half on the other, in such a manner that the two parts form a single picture. You may have, for instance, Harlequin on one side and Columbine on the other, but on turning the card you will see them together. The body of a Turk may be drawn on one side and his head on the other, and, by rotating the card, the head suddenly finds a pair of shoulders to fit it. A sentence may be divided in the same way, or the words, or even the letters, may be divided between the opposite sides of the card: in fact, like the phenakistiscope, the designs applicable to this little instrument are endless.

The third of these instruments, the phantascope, is constructed in accordance with the peculiar power possessed by the eyes of adapting themselves to the distance of the objects they are looking at. Everybody must have noticed that in order to see objects plainly that are placed at different distances we insensibly alter the position and focus of the eyes, and that, consequently, objects even in the same plane as those we are looking at are not perceived by us until something calls our attention to them, and causes us to alter the position and focus of our eyes and fix our gaze on them. For instance, in looking at a canary in a cage, we have but a confused idea of the wires, which we will suppose to be midway between the bird and the observer. But if anything attracts our attention to the wires we lose sight of the bird, or at any rate see it only as a confused mass. If this experiment is made with care, it will be perceived that the object seen confusedly is always double,—a fact that may be verified by interposing the finger between the eyes and any object. When we look at the finger, the distant object will seem to be doubled; if we look at the object, it is the finger that undergoes duplication.

We know by experience that when we look at an object and press one of the eyeballs slightly with the finger, the image of it becomes doubled. The explanation of this phenomenon is not very easy, but it is generally supposed that in the case of ordinary vision the two eyes produce the sensation of a single image in consequence of the two impressions being formed at corresponding parts of each retina, and that habit causes us to see only a single object in such a case. But when the eyes are so disposed as to be capable of seeing distant objects distinctly, the two images formed by a near object are no longer found in the corresponding portions of each retina, and so produce the sensation of double vision. The same thing happens when either of the eyes is momentarily displaced.

These phenomena have given rise to the construction of a very simple instrument, the phantascope, with which many interesting experiments may be performed, and which was invented some years since by Dr. Lake, an eminent physician of New York.

In the middle of one of the edges of a thin piece of wood, say six inches or a foot in length, which serves as a base for the instrument, is fixed a rod fourteen or sixteen inches long, upon which slide a couple of ferules capable of being fixed at any height by means of thumb-screws. Each of these ferules holds a piece of cardboard five or six inches long, and of any convenient breadth, in a horizontal position. The upper card is pierced in a longitudinal direction with a slit rather less than a quarter of an inch broad, and about three inches long; that is to say, a little wider than the distance between the centres of two eyes. The second card has a similar slit of the same length, and corresponding vertically with the one above it; the width, however, in this instance being only about the eighth of an inch. In addition, the lower card should be marked with a fine line drawn across the centre, which we shall call the index.

Things being thus arranged, if we place two similar objects—two A's, for instance—upon the wooden stage of the instrument, about three inches apart, and look at them through the two slits, we shall see them as under ordinary circumstances; but on fixing our eyes intently on the index of the lower card, and gradually raising it, we shall see the two A's become double, the two images of each letter separating themselves more and more the nearer the lower card approaches the upper one, until the last two of the images will coalesce, and appear to be placed on the lower cardboard, the other two remaining in their proper place. The eyes must be kept firmly fixed upon the index, otherwise the illusion disappears immediately, and two A's only are seen in their true position on the base of the instrument. This is an instance of the production of an image in a place where it certainly does not exist. This illusion is seen best when the upper screen is about ten inches from the object, the lower screen being just half-way between; but, as in most of these cases, the distances will differ according to the focus of the observer's eyes. The proper distances once being found, the experiment may be varied in a hundred different ways. For example, instead of two letters and a line we may have two flowers on the stage, and the figure of a flower-pot on the intermediate screen. If the two flowers are painted different colours, they will unite and form a mixed tint. Thus a red and yellow flower will give an orange image, a blue and yellow a green image, and so on. A perpendicular stroke and a horizontal one will give a cross. A few experiments with this little instrument will throw a light upon many of the obscurer points that exist amongst the phenomena of vision, and will show conclusively that the two eyes rarely see in the same manner, and that it is sometimes one, and sometimes the other, that sees most distinctly. A couple of pieces of cardboard, pierced with suitable slits and held in the hand may be substituted for the apparatus above described, but of course they will be much more difficult to use, and will give less satisfactory results.

## CHAPTER VII.

### THE INFLUENCE OF THE IMAGINATION.

The above facts show plainly that optical illusions find their source in the very mechanism of the organs of sight, and that without going farther than the eye itself we may discover numberless examples of these phenomena. We shall presently bring before our readers the innumerable means devised by art for deceiving the sense of sight and impressing us with sensations that are purely imaginary. But before describing these numerous pieces of apparatus we must still remain for a short time within the domain of man's faculties, and describe some of the illusions that we are subjected to by those powers of the imagination that are supposed to hold in check the five senses of the body. Our imagination, however, plays us as many tricks as our eyes, and, like them, is alternately false and true. Touch, taste, smell, hearing, and sight, are all supposed to be under its powerful influence for good or evil; but they are all deceived by it in turn, more especially the sense of sight, which we generally boast of as being the most trustworthy of them all. Were we to describe all the labyrinths into which our imagination is continually leading us, we might easily extend this little volume to one of treble the size. But our purpose is not so much to write a history of all the hallucinations to which the imagination is subject, but to cull from those already existing the most interesting instances in which this great faculty is alternately the victim and the tyrant of the sense of sight.

Amongst many works on this subject we may cite that of Brière de Boismont on "Hallucinations, Apparitions, Visions, &c.," from which we shall draw largely in the following pages. The examples we shall give will be those only in which the victims of the hallucination were in the full enjoyment of their mental faculties, and could healthily analyze the sensations and impressions to which they were subjected.

One of the first of these bears upon those diseases of the eye to which allusion was made in Chapter IV. Towards the end of 1833, a poor washerwoman who was tormented grievously with rheumatic pains gave up her business, and took to sewing for her livelihood. Being but little accustomed to this kind of work, she was compelled to sit over her needle late at night in order to save herself from starving. The unwonted strain upon the eyes soon brought on ophthalmia, which speedily became chronic. Nevertheless, she continued her work, and fell a prey to *diplopia*, or double sight in each eye. Instead of a single needle and thread, she saw four continually at work, everything else about her being similarly multiplied. At first she took no notice of the singular illusion, but at last both imagination and sight joined arms against the judgment, and the poor creature imagined that Providence had taken pity on her forlorn condition, and had worked a miracle in her favour by bestowing on her four pair of hands in order that she might do four times her usual amount of work.

The following is another instance of the passage of illusion into hallucination. A man fifty-two years old, of a plethoric constitution, after having suffered from a defect in his visual functions that caused him to see objects sometimes double, and at others upside down, suddenly showed signs of cerebral congestion, and threatened apoplexy. By proper treatment, however, he was saved for a time from the latter catastrophe, but he became permanently afflicted with strabismus, or squinting, and he suffered from a singular hallucination. His eyelids would contract, and his eyeballs would roll from side to side at more or less distant intervals. On these occasions he imagined he saw the figures of different persons that he knew moving about, and would even follow them outside his door into the other rooms of the house. He was perfectly aware that these appearances were merely the effect of the imagination, but this did not in any way detract from their appearance of reality. The man afterwards died from an attack of apoplexy.

The following examples are also cases of singular optical deception, some of them being so extraordinary as to trench upon the supernatural, and in the days of ignorance would have given those who were their victims the character of unearthly personages.

A certain English painter, who in some sort inherited the palette of Sir Joshua Reynolds, and believed himself superior in many respects to the great master, used to boast that in one year he painted over three hundred portraits, large and small. This fact seemed to Wigan a physical impossibility, and he questioned him closely as to the secret of his astonishing rapidity of execution, for he never required more than one sitting from his patrons. Wigan states that he saw him paint a miniature of a well-known personage in eight hours, which was incomparable in its fidelity to nature and finished execution. Wigan asked him to give him some details of the method he adopted, and he gave him the following answer: "When a sitter presents himself, I look at him attentively for half an hour, sketching the outlines of his features on my canvass during the time. I have no occasion for a longer sitting, and I pass on to some one else. When I wish to continue the first portrait, I take the sitter in my imagination, and I seat him in the chair, where I see him as distinctly as if he were really there, and I can even heighten a tint, or soften down a clumsy form at will, without altering the likeness. I look from time to time at the imaginary figure, and I go on painting. I stop now and then to examine his position, absolutely as if the original were before me; for every time I look towards the chair I see the sitter. This method of proceeding has rendered me very popular; and as I have always succeeded in catching the likeness of my patrons, they have been simply enchanted at my sparing them the tedious sittings exacted by other painters. Little by little I have begun to lose the distinction between the real and imaginary sitter, and I have often maintained stoutly that my patrons had already sat to me on the previous day. At last I became convinced that it was the real sitters that I saw, and thenceforth all became confusion. I suppose my friends took alarm at my hallucinations, for I remember nothing of what happened during the thirty years that I remained in the madhouse. This long period has left no trace on my memory, except indeed the last six months of my confinement. It seems to me, however, that when my friends talk of having visited me I have some vague recollection of the fact; but it is a subject that I do not care to pursue."

The most remarkable feature of the case is, that this artist after a lapse of thirty years resumed his pencil, and painted almost as well as when he was forced by madness to abandon his art.

This faculty of being able to evoke shadows, with which to people one's solitude, may be carried so far as to transform real persons into phantoms. Hyacinth

Langlois, a distinguished artist, living at Rouen, tells us that Talma, with whom he was extremely intimate, confided to him that, whenever he went upon the stage, he had the power, by mere force of will, to cause the clothes and flesh of his numerous auditory to disappear, and become transformed from living beings into so many skeletons. When his imagination had peopled the house with these singular phantoms, the emotion he felt was so great that it gave his dramatic powers still greater force, and enabled him to produce the wonderful effects that have made his name so famous.

Wigan says, that he once knew a most intelligent and amiable man, who could at will evoke his own image. He often laughed at seeing his second self standing before him, the phantom appearing to laugh as heartily as himself. This illusion was for a long time a matter of amusement to him, but at last he became persuaded that he was haunted by his own double. His second self appeared to hold arguments with him continually, and beat him frequently on various points of dispute, a matter which mortified him excessively, as he was rather proud of his powers of reasoning. This gentleman, although always considered as being somewhat eccentric, was never put under the slightest restraint, and at last the creature of his imagination so tormented him, that he resolved not to live through another year. He consequently paid all his debts, arranged his affairs, and waited pistol in hand until the clock struck twelve on the 31st of December, and then deliberately blew out his brains.

In *Abercromby on the Mind* we read an account of the observations made by a gentleman who was the victim of illusions during the whole of a pretty long life. If he met a friend in the street, he was unable to tell at first whether he saw a real human being or only a phantom. By close examination he could detect a difference between the real person and the creature of his imagination, the features of the former being sharper and more defined than those of the phantom; but in general he was obliged to test the reality of the figure he saw by the senses of touch and hearing. He was able, by concentrating his thoughts upon the appearance of any friend, to call up his image; a power which extended even to scenes that he had witnessed. Although he could produce these hallucinations at will, he was powerless in making them disappear; and when once he succeeded in calling forth these creatures of his imagination, he never could tell how long the delusion would last. This gentleman was in the prime of life, a good man of business, and otherwise in a perfect state of mental and bodily health. A member of his family possessed the same faculty, but in a minor degree.

In 1806, General Rapp, when returning from the siege of Dantzic, having occasion to speak to the Emperor Napoleon, walked into his private room without being announced, and found him in such a profound state of abstraction, that he remained for some time unperceived by his imperial master. The General, seeing him thus perfectly motionless, fancied he must be ill, and purposely made a slight noise. Napoleon instantly turned his head, seized the General by the arm, and pointing upwards, exclaimed, "Do you see it up there?" The General, hardly knowing what to say, remained silent; but the Emperor repeated his question, and he was obliged to reply, that he saw nothing. "What," said the Emperor, "you don't see anything? You don't see my star shining before your eyes?" And becoming more and more animated, he went on to say, that the mysterious visitor had never abandoned him, that he saw it throughout all his great battles, that it always led him onward, and that he was never happy but when he was gazing at it.

That such hallucinations have no real existence as far as the eye goes, is proved by the fact of many people who have lost their sight, being subject to them. It is hardly to be wondered at that those who by accident have been deprived of their sight, should wish so ardently to see once more the persons and sights they have taken pleasure in, that they should at last create for themselves illusions of this character. The same thing has frequently occurred with those whose sight is more or less weak. An old man of eighty, who was purblind, never sat down to a table during the last years of his life, without seeing around him a number of his friends who had long been dead, dressed in the costume of fifty years before. This old man had but one eye, which was extremely weak, and wore a pair of green preservers, in the glass of which he continually saw his own face reflected.

Doctor Dewar, of Stirling, mentioned to Abercromby a very remarkable instance of this species of hallucination. The patient, who was quite blind, never walked in the street without seeing a little old woman hobbling on before him and leaning on a stick. This apparition always disappeared when he entered his house.

Similar illusions frequently happen to every one, even the most healthy amongst us, but a little consideration soon puts them to flight. It would be useless to mention the numberless cases in which a square tower has appeared round, or where the landscape has suddenly seemed to recede from the sight. Such illusions as these have been long well known, and appreciated at their proper value; but there are others whose true cause has remained a mystery, until explained by the progress of science, such as the Spectre of the Brocken, the Fata Morgana, and the mirage.

Analogous appearances have been seen in Westmoreland and other mountainous districts, the inhabitants imagining that the air was full of troops of cavalry, and whole armies even; such illusions resulting simply from the shadows of men and horses passing over an opposite mountain being thrown on the fog.

A vast number of different circumstances give rise to these illusions, such as a strong impression, or the recollection of some striking event, which may easily cause them, by the association of ideas. Wigan relates, that being at a *soirée* held at the house of M. Bellart, a few days after the execution of Marshal Ney, the groom of the chamber, instead of calling out the name of *M. Maréchal aîné* (M. Maréchal, senior), announced the arrival of M. le Maréchal Ney. A shudder passed through the company, and many of them declared, that for an instant they saw the face and figure of the dead man in place of those of his involuntary representative.

When the mind is thus prepared, the most familiar objects are transformed into phantoms. Ellis relates an anecdote of this kind, which he heard from an eye-witness, who was a ship's captain of Newcastle-on-Tyne. During a voyage that he made, the ship's cook died. Some days after the funeral, the chief mate came running to him in a great fright, with the news that the ship's cook was walking on the water, astern of the vessel, and that all the crew were on deck looking at him. The captain, who was angry at being disturbed with so nonsensical a tale, answered sharply, that they had better put the ship about and race the ghost to Newcastle. His curiosity, however, was presently aroused, and he went upon deck and looked at the spectre. He frankly avowed that for some moments he saw what really appeared to be his old shipmate, just as he knew him in life, with his walk, clothes, cap and figure perfectly resembling those of the dead man. The panic became general, and every one was struck motionless for a time. He had the presence of mind, however, to seize the helm and put the ship about, when as they neared the ghost, they found the absurd cause of their fright was a broken mast from some wreck, which was floating after them in an upright position. If the captain had not boldly sailed up to the supposed ghost, the story of the dead cook walking upon the water would have continued to this day to terrify half the good inhabitants of Newcastle.

Such facts as these are innumerable, and we shall mention a few more which will explain a host of stories found in various ancient and modern authors.

Ajax was so angry at the arms of Achilles being awarded to Ulysses, that he became furious, and, seeing a herd of pigs, drew his sword and fell upon them, taking them for Greeks. He next seized a couple of them and beat them cruelly, loading them at the same time with insults, imagining one of them to be Agamemnon, his judge, and the other Ulysses, his enemy. When he came to himself, he was so ashamed at what he had done, that he stabbed himself with his sword.

Theodoric, blinded by jealousy and yielding to the base solicitations of his courtiers, ordered that Symmachus, one of the most upright men of his time, should be put to death. The cruel order had hardly been executed, when the king was seized with remorse, and bitterly reproached himself with his crime. One day a new kind of fish was put upon the table, when the king suddenly cried out that he saw in the head of the fish the absolute resemblance of that of his victim. This vision had the effect of plunging the king into a state of melancholy that lasted his whole life.

Bessus once, when surrounded by his guests and giving himself up to the enjoyment of the feast, ceased suddenly to listen to the flattering speeches of his courtiers. He apparently listened with great attention to some sound that was heard by no one else, and suddenly leaping from his couch, mad with rage, he seized his sword and rushing at a swallow's nest that was near, beat it down, killing the poor birds inside it, crying out that these insolent birds dared to reproach him with the murder of his father. Surprised at such a sight, his courtiers gradually disappeared, and it became known some time afterwards that Bessus was really guilty, and that the senseless action he had performed simply resulted from the voice of conscience.

The illusions of sight and hearing are often found to take an epidemic form, and historians relate an immense number of anecdotes bearing on this particular phase of self-delusion. One of the commonest of them is that which transforms the clouds into armies and figures of all kinds. Religious prejudices, optical phenomena, physical laws that are still unknown, dangerous fevers, derangements of the brain, afford a natural explanation of these hallucinations.

We have borrowed most of these examples from Brière de Boismont's works, for the special purpose of showing how easy it is to deceive the imagination, and to demonstrate the facility with which the sense of sight is led astray without the intervention of complicated apparatus. In addition, we may quote instances from Brewster, showing the ease with which the imagination enables us to see distinct forms in a confused mass of flames, or in a number of shadows superposed upon each other. This great philosopher gives us an anecdote of Peter Heamann, a Swedish pirate and murderer. One day that his crew were repairing some unimportant portion of the ship, after having pitched the place well he took the brush in order to tar the other parts of the vessel, which were much in want of such treatment; but as soon as he spread the pitch over the timbers of the ship, he was thunderstruck at seeing apparently reflected in its shining surface the image of a gallows with a headless man beneath. The head belonging to the body was lying before it, and the body itself was depicted with every limb—legs, thighs, and arms—perfect. He frequently told his crew of these illusions, adding that it was evidently a prediction of the fate in store for them. He was often in such a state of terror, that on calm days he would drop down into the hold and wrap himself up in a spare sail in order not to catch sight of the horrible image that he constantly saw in the shining surface of the tar.

The imagination really seems to create for itself a sort of mental visual organ which is in intimate relation with that of the body, and which often takes its place so efficiently—as in the case of dreams—that the mind is utterly unable to perceive the substitution. It is on account of this that practical opticians are so unsparing in their endeavours to predispose their spectators to being deceived.

When both the body and mind are healthy, the relative intensity of the two kinds of impressions is very unequally divided, mental images being more evanescent and comparatively weak, and with persons of ordinary temperament incapable of effacing or disturbing the reflections of visible objects. The affairs of life could not go on if the memory introduced amongst them brilliant representations of the past in the midst of ordinary domestic scenes or the objects familiar to us. We may account for this by supposing that the set of nerves which carries the efforts of the memory to the brain cannot execute their functions at the same time as those which take cognizance of the images reflected on the retina. In other words, the mind cannot accomplish two separate functions at one and the same time, and the mere act of directing the attention to one class of subjects causes all others to become instantly imperceptible. The exercise of the mind in these instances is, however, so rapid that the alternate appearance and disappearance of the two different impressions is completely unnoticed. Thus, for instance, while looking at the dome of St. Paul's, if our memory suddenly evokes the image of some other object, Mont Blanc for instance, the picture of the cathedral, although still depicted on our retina, is momentarily effaced by the effort of the will, although we may not change the position of our eyes during the time. While the memory continues to dwell on the picture it has called up, it is seen with sufficient distinctness, although its details may be somewhat misty and its colours confused; but as soon as the wish to see it passes away the whole disappears, and the cathedral is seen in all its former distinctness.

In darkness and solitude, when surrounding objects produce no images that can interfere with those of the mind, these latter are more lively and distinct: and when in addition we are half asleep and half awake, the intensity of mental impressions approaches that of visible objects. In the case of persons of studious habits who are continually employed in mental effort, these images are more distinct than with those who follow the ordinary avocations of life, and during their working hours rarely see the objects round them. The earnest thinker, absorbed by meditation, is in a manner deprived for the time of the use of his senses. His children and servants pass in and out of his study without his seeing them, they speak to him without his hearing them and they may even try to rouse him from his reverie without success; and yet his eyes, ears, and nerves received the impression of light, sound, and touch. In such instances, the mind of the philosopher is voluntarily occupied in following out an idea which interests him profoundly; but even the most unlearned and thoughtless of us sees the images of dead or absent friends with his mind's eye, or even fantastic figures which have nothing to do with the train of thought he may be pursuing. It is with these involuntary apparitions as with spectres of the imagination: although they are intimately connected with some thought that has passed through our mind unperceived, it is impossible to trace a single link of the chain connecting them together.

# PART II.

## THE LAWS OF LIGHT.

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## CHAPTER I.

### WHAT IS LIGHT?

Everybody knows the effects of the action of light, without, however, understanding precisely what constitutes light itself. Any formal definition would rather puzzle than help the student; we must therefore content ourselves with saying that light is that effect of force which causes us to perceive external objects.

A man who was blind from his birth, and upon whom the operation for cataract had been successfully performed, had accustomed himself for a long time to imagine the nature of those unknown phenomena that his affliction had prevented him from observing. He had arranged in his mind the various definitions that had been given to him as to the nature of light, and having combined them, he fancied he had acquired some notion of what the sense of vision really meant. But what was the astonishment of the surgeon who had restored to him his fifth sense, when he asked him to give his opinion upon the effects of light, to see him take up a lump of sugar and reply that it was under that form that he had imagined it to himself.

As for us who have the happiness of possessing the sense of sight, we know this mysterious agent more by the enjoyment that we have derived from it, than from any analysis we have made of its nature. It is an endless chain that connects us with the entire universe; a bond that laughs at distance and spans the abysses of space. By means of light we can appreciate the beauties of hue and form, and by its power we touch as it were the inaccessible. It constitutes the most intimate connexion between ourselves and external objects—a connexion that seems even to alter our temper, disposition, and character, according to the variations of its intensity. The dull and foggy days of winter, those days when sleet and rain struggle in the atmosphere, spread like a veil over us, and throw a shadow upon our life. The return of the bright spring sun, the reappearance of light and blue sky, on the contrary, open up our hearts and minds, gay nature enchants us once more, and a feeling of fresh happiness prepares us for the coming glories of the newly risen year.

This intimate connexion between the light of heaven and the human mind, hallowed as it is by our desire to rise towards the Source of all light, might be made the subject of many eloquent pages; and it would be an interesting and useful task to show the gradual progress of mankind from those ancient people who trembled at the approach of darkness, and who fervently saluted the dawn with prayers and praises, down to the philosophers of the present age, who investigate its effects with so much reverential joy. But we must cease paying any more attention to the superficial action of this marvellous force which in these latter days has become, in the hands of man, the source of so many illusions and the origin of a complete world of rich and brilliant pictures, but which after all only exist in the imagination.

It was believed for a long time that light was a compact mass of tiny particles emitted by luminous bodies, which struck our eyes and so produced the phenomenon of vision. These particles or molecules were naturally thought to be extremely minute, and the objects illuminated by them were supposed to throw them off as if they were endowed with elasticity. Under this hypothesis, light was a material body. The illustrious Newton was the first propagator of this theory; the last was M. Biot, a French philosopher, lately dead.

The undulatory theory has now-a-days completely superseded the corpuscular hypothesis. It was first started about the year 1660 by the Dutch philosopher Huyghens, who has left behind him numerous treatises on optics, and the properties of light, as well as a curious account of the inhabitants of the other members of the solar system, including a minute description of the various planetary manners and customs. At the beginning of the present century, Fresnel showed, by the most brilliant discoveries the superiority of this theory, and shortly after Arago confirmed him in his demonstrations. According to the undulatory hypothesis, light is not a mass of molecules emitted by a luminous body, but simply the vibration of an elastic fluid which is conceived to fill the whole of space. A comparative example may assist you in understanding this theory more clearly. If you throw a stone into a smooth piece of water, there will form around the point where the stone fell, a series of circular undulations, starting from the centre and gradually enlarging themselves. If a loud noise is suddenly heard, the same effect is produced round the point from whence the sound proceeds. A series of waves are formed which spread not only horizontally, as on the surface of the water disturbed by the stone, but in every direction. In fact, in the case of sounds, the waves are so many gradually increasing spheres. In the case of light, when a luminous body is placed in space, the ether which surrounds it is thrown into a state of vibration, and the motion is immediately propagated in all directions, with extreme velocity. It is these undulations that produce upon our eyes the sensation of light. We may therefore say that light, like sound, is movement, while darkness, like silence, is absolute rest.

Many people still believe that light is propagated instantaneously, and cannot bring themselves to imagine that we do not see a flame the moment we light it, but only an instant after. I have myself spoken to well-educated people possessed of good judgment and a certain amount of elemen ary knowledge, who could never bring themselves to believe that we see the stars, not as they now exist, but as they appeared at the particular moment when the luminous wave by which we are enabled to perceive them left their surface, and which only reaches us after travelling through space a certain number of years, days, or hours, according to their distance. It is extremely useful and interesting to form a correct idea upon the way in which light is propagated.

The determination of the prodigious quickness with which the waves of light move through space, says Arago, is undoubtedly one of the happiest results of modern astronomy. The ancients believed that it moved with infinite velocity, and their view of the subject was not, like so many of the questions relating to physics, a mere opinion without proof; for Aristotle, in mentioning it, brings forward the apparently instantaneous transmission of daylight. This notion was disputed by Alhazen, in his *Treatise on Optics*, but only by metaphysical weapons, which were again opposed by several very worthless arguments, by his commentator, Porta, although he admitted the immateriality of light. Galileo seems to have been the first amongst modern philosophers who endeavoured to determine the velocity of light by experiment. In the first of his dialogues, *Delle Scienze Nuove*, he announces by the mouth of Salviati, one of the speakers present, the ingenious means he had employed, and which he thought quite sufficient to solve the question. Two observers with lights were placed at the distance of one mile from each other; one of them extinguished his light, and the other as soon as he perceived it extinguished his. But as the first observer saw the second light disappear the instant he had extinguished his own, Galileo concluded that light was propagated instantaneously through a distance double that which separated the two observers. Certain analogous experiments that were made by the members of the Academy *Del Cimento*, but at three times the distance, led to precisely the same conclusions.

These attempted proofs seem at first sight to be absurd, when we think of the vastness of the problem to be solved; but we must judge these experiments with less severity, when we consider that almost at the same epoch, men of such well-deserved repute as Lord Bacon believed that the velocity of light, like that of sound, was sensibly altered by the force and direction of the wind.

Descartes, whose theories upon light had so much analogy with those known under the name of the undulatory hypothesis, believed that light was transmitted instantaneously throughout any distance, and endeavours to prove his position by proofs that he thought he had obtained whilst observing an eclipse of the moon. It must be acknowledged, however, that his very ingenious train of reasoning proves that whether the transmission of light is instantaneous or not, it is at least too considerable to be determined by experiments made on the earth, like those of Galileo, and which he vainly hoped would have solved the question.

The frequent occultations of the first satellite of Jupiter, the discovery of which was almost consequent upon that of lenses, furnished Römer with the first means of demonstrating that light was propagated by perceptible degrees.

In tracing out the history of human knowledge, says Dr. Lardner, we have frequently to point out with some little surprise, joined to a feeling of profound humility, the important part played by chance in the advancement of science. In searching zealously after mere trifles which, when found, are of no consequence, we frequently lay our hands on inestimable treasures. The frequency of this fact impresses the mind with the notion that some secret and unceasing power exists, in accordance with which human knowledge and science are continually progressing. It is in physical, as in moral philosophy. In our ignorance—like the dog mentioned by Æsop, which, seeing in the water the reflection of the prey it held in its mouth, dropped the substance and tried to seize the shadow—we are continually searching after trifles; but, more fortunate than the animal of whom we have been speaking, the shadow that we try to seize is often transformed into a rich treasure. We can say with every confidence that "the Providence which shapes our ends," knows our wants better than we do ourselves, and bestows on us the things we *ought to have* asked for instead of those we *have* asked for. We shall find a very simple proof of this in the history of the discovery of the velocity of light.

A short time after the invention of the telescope and the consequent discovery of Jupiter's satellites, Römer, a celebrated Danish astronomer, was engaged in a series of observations, the object of which was to determine the time which one of these bodies took to revolve round its planet. The method employed by Römer was to observe the successive occultations of the satellite, and to notice the interval that elapsed between each of them. But it at last happened that the interval between the two occultations, which was about forty-five hours, became prolonged by periods of 8, 13, and 16 minutes, during that half of the year when the earth was receding from the planet, while it became proportionally cut short during the rest of the year. Römer was struck by a happy idea; he suspected instantly that the moment when he remarked the disappearance of the satellite was not always coincident with the instant when it really took place, but that it sometimes appeared to happen later—that is to say, after an interval of time sufficiently long to allow the light that had left the satellite immediately after its disappearance, to reach the eye of the observer. Hence it became evident that the farther off the earth was from the satellite, the longer was the interval of time between its disappearance and that of the arrival of the last portions of its light upon the earth; but that the moment of the disappearance of the satellite is that of the commencement of the occultation, and that the moment of the arrival of the last portions of light is that when the commencement of the occultation is observed.

It was thus that Römer explained the difference between the calculated and observed time of the occultation, and he saw that he was on the threshold of a great discovery. In a word, he saw that light propagated itself through space with a certain velocity, and that the fact we have just mentioned furnished the precise means of measuring it.

Thus the occultation of the satellite was retarded one second for every 185,000 miles that the earth is distant from Jupiter; the reason being, that a ray of light takes a second to travel this distance, or, in other words, because the velocity of light is at the rate of 185,000 miles per second.

It must be remembered when considering this subject, that in any system of undulations or vibrations, no matter through what medium they are propagated, their movement is simply a change of form, and not a transmission of matter. The waves which spread round a central point when a stone is thrown into the water, give one the idea that the water which forms the wave really moves towards the observer. But it is not so, as may be readily proved by placing on the surface a floating body, which we shall find is but little, if at all, influenced by the undulations of the water. The appearance of rolling waves given on the stage by means of a painted cloth, to which an undulatory motion is given, is an instance of this apparent movement. In the case of the floating body, which would follow the movements of the water, we shall find that wave after wave rolls to the shore, in the same way as the painted marks on the imitation sea keep their place, although the cloth itself undulates. The waves of the sea even appear to the eye to be endowed with a progressive motion, but an instant's observation will convince us of our error; for if such were the case, every object floating on the ocean would be gradually carried on shore. A vessel floating on the waves is not carried along by them, at least not until it reaches within a few yards of the shore, where the water is really in motion; but out in the open sea a floating body will alternately rise on their crests, and fall into the valleys that separate them. The same effect may be observed with any object floating on the water. If, however, in addition to being in a state of undulation the sea is really in motion from the effects of a current, or from any other cause, the floating object will of course be carried along by it—in fact, the two movements are quite independent of each other, and may take place in similar or contrary directions. It is very important that we should be able to distinguish at an early period the exact difference between true movement and mere undulation; and we must remember that although the waves of light are propagated at the rate of 185,000 miles a second, still there is no transmission of any material substance at this marvellous rate. The same observation applies to sonorous vibrations transmitted through the air.

Thus we are constrained to admit peaceably the truth of the undulatory hypothesis as compared with the corpuscular theory. I say *peaceably*, because I am forcibly reminded by the contrast I have made between the two theories of an anecdote related of one of the greatest monsters who ever walked this earth, but who was afterwards struck down in the midst of his power by the hand of a weak girl. I allude to the infamous Marat, who one day presented himself at the house of Dr. Charles, a celebrated natural philosopher, of the time of the first French Republic, in order to advance certain notions of his own against the optical principles that Newton has left behind in his *Principia*, and other works—also, to oppose certain theories connected with electrical science. Dr. Charles, who did not approve of Marat's wild notions, undertook to convince him of his errors. But instead of discussing the matter peaceably, Marat allowed himself to be carried away by his temper, which was naturally very violent. Every argument advanced by his antagonist seemed to increase his rage, until at last he lost all control over himself, drew his small sword, and rushed upon his opponent. The doctor, who was unarmed, had to exercise all his powers to prevent himself from being wounded, and being much more stoutly built than Marat, he at last succeeded in throwing him down, and wresting his sword from him, which he immediately took care to break. Whether it was the violence of the fall, the shame he felt at being doubly beaten, or the effects of his fit of passion, does not appear, but Marat fainted. Assistance was called, and he was carried home to his house, his offence against all the laws of propriety being forgiven by his more talented and better-tempered adversary.

There are many persons, no doubt, whom we should astonish, and possibly enrage, by asserting positively that we could cause darkness by means of light, that silence could be produced by sound, or cold by heat. These are daring paradoxes, and at first sight appear almost as reasonable as that of Anaxagoras, a Greek philosopher, who asserted that snow was black. But as I hope that most of my readers do not possess the passionate temper of the French tribune, I will confide to them a little secret that will make these paradoxes plain. It is called by natural philosophers the theory of interference.

The experiments connected with this subject are exceedingly difficult to perform, and require the aid of apparatus far beyond the reach of the ordinary student. It is a case where theory and description are much easier than practice.

If a ray of electric light is thrown upon a screen, it is possible to direct another ray upon the same spot in such a manner that they will extinguish each other mutually. The reason of this phenomenon may be understood, if we remember that light is caused by undulatory movement, and that by opposing two series of waves to each other in such a manner that their vibrations coming in contact produce rest, we can easily see how the waves of light of one ray may be stopped by those of a second.

Going back to our illustration of the eddies on a pool of water, it is easy to prove that by throwing a second stone into the water we form another series of undulations; which are mutually destroyed when they encounter each other. It is the same with the peculiar fluid which, existing throughout space, is thrown in a state of undulation by incandescent bodies; by opposing one set of waves to another we obtain rest as a result.

This fact was first observed by Grimaldi in 1665, and Dr. Thomas Young was the first to offer an explanation. Fresnel used it with great success at the beginning of the century to demonstrate the truth of the undulatory theory, by showing that it could not be explained by any other.

# CHAPTER II.

## THE SOLAR SPECTRUM.

THE white light that the glorious orb of day spreads over the face of nature is the original source of all those brilliant and sombre colours with which the works of the Creator are beautified. To the rays of the sun we owe not only the whiteness of the lily, but the scarlet of the field poppy, the modest blue of the timid violet, the splendour of the peacock's plumage, the cool green of the meadows, and the purple and gold of the distant mountains. For, as we have hinted before, this white light, which seems of itself so destitute of colour, is productive of every hue that the eye of man is capable of appreciating.

It may seem that I am bestowing too much praise upon our own sun; but if you are surprised that I should seek to exalt this brilliant globe of ever-burning fire, I must ask you to recollect, that though the starry heavens are full of suns as vast and important as ours, and possibly affording brilliant colourless light to worlds full of inhabitants, there are others that give forth rays that are far from being white. Some are as green as emeralds, others are as blue as sapphires, while others give out a warm light like a ruby or topaz. The worlds which surround these can only receive light of a certain colour, or at any rate they are restricted to a few shades and hues. Imagine living in a world where everything was always *couleur de rose*, or in which the inhabitants were continually looking blue! A residence in either of them for a short time would undoubtedly cause us to appreciate the relative value of our own little sun, small as it is in comparison with some of the mighty orbs floating about in space.

The fact that the light of the sun is the source of all the changing hues to be found on the surface of the earth season after season was first discovered by Newton, and his experiments are easily repeated with a very few and inexpensive appliances.

A small round hole is made in the window-shutter of a room, facing the sun, and the pencil of light proceeding from it is allowed to fall upon the surface of a three-sided prism, held in a horizontal position, and placed at a distance of a few inches from the aperture (fig. 5, Frontispiece). The pencil of light does not pass through the prism as if it were a plate of glass with parallel sides, but in virtue of the laws of refraction, of which we have already spoken, it is turned out of its natural course, and is thrown upon the wall in the direction indicated in the figure. The pencil of light is not only turned aside, but it is also widened out into a band which is truly painted with all the colours of the rainbow, every tone and hue being of the most marvellous brilliancy. This long coloured stripe, which constitutes one of the most beautiful sights that the science of optics can afford us, is known to scientific men by the name of the solar spectrum.

Before going into the causes that produce these colours, let us first examine their number and position. Beginning at the top, we shall find that they run in the following order:—Violet, indigo, blue, green, yellow, orange, red. The red being lowest is called the least refrangible of them all; or, in other words, in passing through the prism it was bent less out of its course than its companions. Violet, being at the top, is of course the most refrangible. The cause of the separation of the colours of white light is consequently only the effect of their individual character. They were, so to speak, so many streams flowing together until an unexpected deviation in their course caused them to separate. This change in the direction of their flow brought out their personal individuality, and they at once became completely disunited.

Every single tint in the prismatic spectrum is simple, and cannot be decomposed. This may be shown by passing any of them through another prism, when it will be found that no change will take place in the colour or size of the pencil. Hence those worlds already spoken of, whose light of day is red, blue, or green, never see any colours but these. (Fig. 6, Frontispiece).

It is just as easy to reunite the colours into which white light is decomposed, by applying a second prism in a reversed position to the pencil of coloured light, as it is to separate them in the first instance. The method of accomplishing this is shown in fig. 7, Frontispiece.

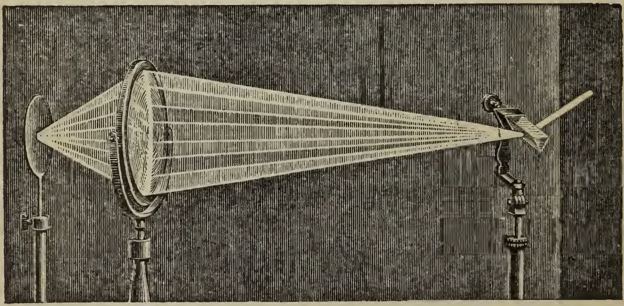

FIG. 8.—The Recomposition of Light.

Another experiment in the same direction consists in reuniting the colours by causing them to pass through a double convex lens, behind which is placed a screen of ground glass, or a card (fig. 8). By advancing and withdrawing this screen we can easily find the exact spot where the rays reunite, and form a dazzling spot of white light. This point is called the focus, from a Latin word, signifying "fire-place," a term which will put the student in mind of the frequently repeated experiment of burning a piece of paper with an ordinary magnifying-glass.

Instead of using a lens, you can, if you please, employ a concave mirror, using the ground glass or card-

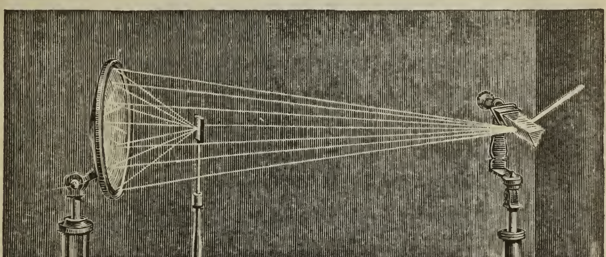

Fig. 9.—Recomposition of Light by means of a Concave Mirror.

board screen, as before. The colours reflected by the mirror unite at its focus, and produce a brilliant white spot in just as conclusive a manner as in the other experiment.

A fourth experiment, which is somewhat more difficult for the student to accomplish, consists in causing every one of the seven different colours to be reflected from a separate mirror.

The mirrors in this case are concave, and are so mounted as to be capable of being moved in any direction. By directing each of the seven rays, one by one, upon the same point, you may observe the gradual decomposition of the coloured light. The effect obtained by adding the last colour to the mixture is quite magical, the white circle being produced from two brilliantly-coloured spots.

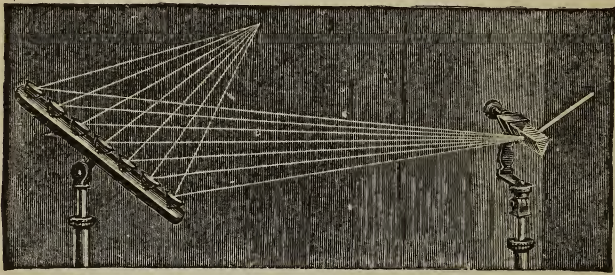

Fig. 10.—Recomposition of Light by means of a number of Mirrors.

A fifth experiment, first devised by Newton, is also within the reach of the student. On a disc of cardboard the centre and border of which have been previously painted black, are pasted seven strips of paper, painted as nearly as possible of the same colour as the components of the spectrum—or if the student is anything of an artist he may paint the disc in imitation of the spectrum, carefully shading off the tints into each other. If the disc be now rapidly rotated the colours will disappear, and a greyish hue will be seen, which will approach more closely to white, the nearer the colours on the disc are to those of the spectrum. This experiment is not precisely the same in principle as the preceding ones, for it is evident that the colours on the disc do not mix, but only the impressions they form upon the retina. We have already said that such impressions remain on the eye for one-tenth of a second or thereabouts; the disc must therefore revolve at least ten times a second, or the effect will not be perceived.

From these experiments it follows that the colours with which all natural substances are clothed, ought not to be looked upon as belonging to them absolutely, but only as a property dependent on the reflection and absorption of light from their surfaces. The leaves of

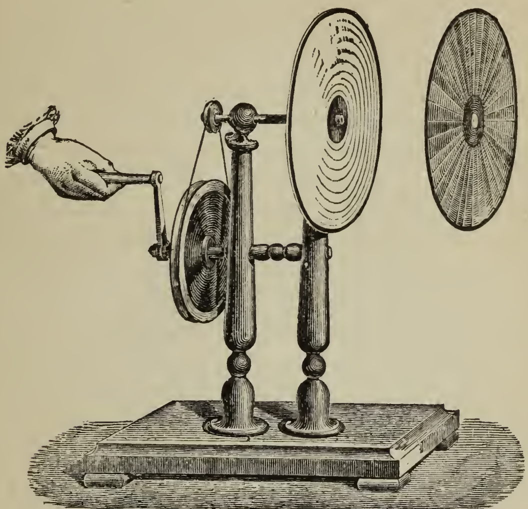

Fig. 11.—Newton's Disc.

plants, for instance, must not be regarded as being really green in themselves, but as being capable of absorbing certain portions of light, and reflecting others. Grown in the dark, the green substance contained in the plant and its leaves becomes white, and no longer possesses the property of absorbing red light, and reflecting green. A green leaf placed in red light becomes almost black, from its power of absorbing light of that colour; in the blue it reflects a much greater proportion of the coloured ray. A very striking experiment may be performed with a substance known to chemists as the iodide of mercury. If a little of this salt, which is of a brilliant red, be placed in a watch-glass, and heated over a spirit-lamp, it will gradually sublime, and a card held over it will be covered with a number of light yellow crystals. In this case no change of composition has taken place, but simply a change in the power the salt possesses of reflecting some rays and absorbing others. By simply scratching the surface of the card with a pointed piece of wood, the yellow crystals become transformed once more into the red variety; not only this, the transformation gradually spreads, like a red cloud, over the whole of the deposit. There are some other salts known to chemists which possess the property of dichroism, or double colour. The double cyanide of platinum and barium, for instance, appears violet when viewed in one direction, and yellow in another. Change of temperature is often sufficient to change the colour of bodies—white oxide of zinc, for example, becomes bright yellow when heated. Such instances might be supplied *ad infinitum*, but enough has been said to prove that colour, after all, is only an appearance, and not an essential property of bodies.

We have already spoken of complementary colours, or those which it is necessary to add together in order to produce white light. Blue, for instance, is complementary to orange, red to green, violet to yellow, and *vice versa*. But it is not by the aid of the palette that this can be proved, for in the case of coloured pigments the arrangement of their atoms interferes in some way with the success of the experiment, and it is only by means of the colours of the spectrum that such recompositions can be effected.

Although most philosophers consider that there are seven colours in the spectrum, there are others who do not admit it, but assert that there are really only three, red, yellow and blue—which by the superposition of their edges produce the intermediate hues of green and orange. Perhaps it would be nearer to the truth to say that the spectrum is composed of an infinite number of colours of different hues.

We have already stated that every one of these colours is indecomposable, and that there are certain worlds illuminated by a single colour only, instead of possessing the infinite number of tints enjoyed by the inhabitants of the solar system. An idea of this effect can easily be gained in a very simple but surprising manner by inserting panes of glass of different colours in the hole of the shutter of a dark room. If the light is yellow, you will find that all those objects that are capable of reflecting yellow light are coloured by it, while those which are bright red or blue become almost black by absorbing the only light present. If we could procure an object which was perfectly complementary in colour to the yellow glass, it would appear perfectly black. The same experiment may be repeated with the other colours. After remaining in this coloured light for some time, if you suddenly pass out into daylight the complementary colour will tinge everything around you.

Instead of using a room into which coloured light only is admitted, lamps burning with a coloured flame may be employed. Brewster mentions the following experiment, which is a very striking one:—Fill a spirit-lamp with alcohol in which has been dissolved as much common salt as the spirit will take up; on being lit it will be found to burn with a livid yellow flame. A room lighted entirely with one or two lamps of this kind will form a laboratory for some very singular experiments. It should, if possible, be hung with pictures in water and oil colours, and the persons present ought to wear nothing but the brightest colours, and the table be ornamented with the gayest of flowers. The room being first lighted with ordinary daylight, the lamps above mentioned should be brought in, and the daylight carefully excluded, when an astonishing metamorphosis will take place. The spectators will be hardly able to recognise each other; the furniture of the room, and every other object contained in it, will reflect but a single colour. The flowers will lose their brilliant tints, the paintings will appear as if they were drawn in Indian ink. The brightest purple, the purest lilac, the richest blue, the liveliest green, will be converted into a monotonous yellow. The same change will take place in the countenances of those present; a livid paleness will spread over their faces, whether young or old, and those who are naturally of an olive complexion will hardly appear changed at all. Every one will laugh at the appearance of his neighbour's face, without thinking that he is just as great a subject of laughter to them. If, in the midst of the amusement caused by this experiment, the light of day is admitted at one end of the room, the other end being still lighted with the salt-lamp, every one will appear to be half-illuminated with the livid colour which has caused so much surprise, the other portion of their figure and clothes being of the natural hue. One cheek, for instance, will appear animated with its usual brilliancy, while the other will be that of a corpse; one side of a lady's dress will be brilliant blue or green, as the case may be, the other a colour that it would puzzle an artist to give a name to. The experiment may be varied by admitting the white light through several small holes in the shutter of the room, every luminous spot painting the place where it falls in its natural colours, and the yellow spectators will become spotted with the most singular tints and hues. If a magic-lantern is used to throw on the walls of the room and the clothes of the company any luminous figures, such as those of flowers or animals, they will be coloured with these figures in the tint of the wall or fabric upon which they fall, yellowish colours of course escaping the transformation. If nitrate of strontia be substituted for the salt, a crimson tint will be spread over everything. In fact, a lamp prepared in this way will form a source of endless amusement. It is not necessary to use alcohol for the purpose; wood-spirit or methylated alcohol will serve the purpose equally well. If a lamp is not to be had, a few pieces of cotton-wool, tied on wires and dipped in the salted spirit, will do almost as well.

# CHAPTER III.

## OTHER CAUSES OF COLOUR.

THE colours of the spectrum are to the sense of sight what the tones of the gamut are to the sense of hearing. On the one hand, the differences in the lengths of the sonorous waves constitute the variety of note perceptible by the ear; on the other, the differences in the lengths of the luminous waves constitute the variety of colour perceptible by the eye. By and by, we shall learn both the length and rapidity of these vibrations, but it will be as well first to describe the experiments made in this direction by the immortal Newton himself.

Every one has, doubtless, at one period of his life, amused himself with blowing soap-bubbles by means of a tobacco-pipe and a little lather—a sufficiently childish amusement, you will possibly say, but one narrowly connected with the most intricate secrets of the science of optics. These little globes, so fragile that they disappear in a breath, hardly seem worthy of the attention of a thinker, and still less the examination of a philosopher; but it is nevertheless true that Newton made experiments on the colours shown on the surface of these apparently insignificant objects which ended in the most brilliant discoveries, just as on seeing an apple fall he began a train of thought which only terminated in the enunciation of the hypothesis of the earth's power of gravity.

All transparent substances, whether liquid, solid, or gaseous, become coloured with the most brilliant hues as soon as they are reduced to plates of extreme thinness. In the soap-bubble it is the oleaginous particles floating on the surface which thus become coloured, but Newton showed that thin plates of air were similarly capable of showing colour, and that the thinner the plates were the more brilliant were the tints. We may see this in the soap-bubble, which becomes more beautiful as it gets larger and thinner. By placing a convex lens of large size on a flat plate of glass, Newton observed that rings of different colours were formed round the spot where the two pieces of glass touched.

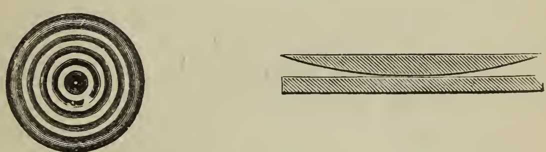

Fig. 12.—Newton's Rings.

By measuring the convexity of the lens and the diameter of the various rings, Newton was enabled to tell to a minute fraction the exact thickness of the plate of air corresponding to the different colours. The glasses being placed in position, a ray of a particular colour—red, for instance—was thrown upon the surface. The result was a black spot at the point where the two surfaces touched, and surrounding it at various distances were several rings alternately red and black. Calculating the thickness of the plates of air at the part where the dark rings made their appearance, Newton found that their dimensions were in the proportion of the even numbers two, four, six, eight, &c.; while the red rings showed figures corresponding to the odd numbers. Although trammelled by the corpuscular theory, Newton's deductions from these experiments show that they can only be accounted for by the undulatory hypothesis. Thus the thickness of the plate of air at the first red ring is that of the red wave, the thickness at the second that of two red waves, and so on; so that in order to arrive at the thickness of the red wave we need only measure the distance between the portions of the glasses where the first red ring occurs.

This experiment was applied to the measurement of all the waves. Whenever they were reflected on the glasses a parallel series of rings was formed, but it was found that the first ring was more or less distant from the central spot, according to the colour used. The red ring was the largest; the orange, yellow, green, blue, indigo, and violet, following in the same sequence as in the spectrum. The word "thickness" seems hardly fit to apply to dimensions arrived at by Newton in his experiments, so infinitely small do they appear to be, yet their correctness has never been impugned, although the experiments have been repeated by the philosophers of all countries. The waves of red light are so small that 40,000 of them go to an inch, and those of violet light situated at the other end of the spectrum are still smaller, measuring only the 60,000th part of an inch.

The waves of the other colours are between these two, while the wave of white light, which is a mixture of them all, is just half-way between the two.

Thus was the physical cause of the various hues of colour discovered by this great man, revealing as it does the singular and mysterious analogy between sound and light. The rays of light, like the waves of sound, produce a different effect, according to their length, by causing quicker or slower pulsations in the nerves of sight, just as musical sounds vibrate upon the drum of the ear with different velocities.

This is not all, for the relationship between sound and light does not cease here: we have as yet only spoken of the size of the undulations, and have only shown how their dimensions are connected with the sensation of colour; but there are other things to be considered, for on investigation we find that not only do the different coloured waves vary in the length of their undulations, but also in the number that take place in a given time.

The perception of sound is produced by the action of the drum of the ear, which vibrates sympathetically with the pulsations of the air that have been originated by the vibrations of the sounding body; and the perception of light is produced in a similar manner by the vibrations originating in a luminous body, and propagating themselves through the luminous ether until they reach the nerves of sight. The number of these pulsations taking place in the eye has been accurately determined in the following manner. Let us suppose that we are looking at a coloured object—let us say, a red railway signal-lamp; from the lamp to our eye there flows a continuous line of luminous undulations; these undulations enter the eye and become depicted on the retina. For every wave that passes through the pupil, there is a separate and corresponding vibration of the optic nerve, and the number of these vibrations that take place in the course of a second can be easily calculated if we know the velocity of light and the breadth of the waves. We have before found that light travels at the rate of 185,000 miles per second; it therefore follows, that a series of undulations 185,000 miles long pass through the pupil every second; consequently the number of vibrations per second is arrived at by calculating how many waves measuring the 40,000th of an inch—that being the length of a wave of red light—are contained in 185,000 miles. The following table, showing the number of waves passing into the eye per second for the different colours, will interest the student:—

| | | |
|---|---|---|
| Extreme red . . | 458,000,000,000,000 | waves per second. |
| Red . . . . . | 477,000,000,000,000 | " |
| Orange . . . . | 506,000,000,000,000 | " |
| Yellow . . . . | 535,000,000,000,000 | " |
| Green . . . . | 577,000,000,000,000 | " |
| Blue . . . . | 622,000,000,000,000 | " |
| Indigo . . . . | 658,000,000,000,000 | " |
| Violet . . . . | 699,000,000,000,000 | " |
| Extreme violet . | 727,000,000,000,000 | " |

Whatever theory we may adopt to explain the phenomena of light, we arrive at conclusions that strike the mind with astonishment and admiration. According to the corpuscular hypothesis, it was supposed that the molecules of light were endowed with the power of attraction and repulsion, that they possessed poles and centres of gravity like the earth, and that they had other physical properties that could only be given to ponderable matter. Starting with these notions, it is difficult to divest oneself of the idea of sensible size, or to induce the mind to conceive particles so extremely small as those of light would necessarily be if the theory of emission were accepted. If a particle of light weighed a grain, it would produce by means of its enormous velocity the effects of a cannon-ball weighing 120 lbs., travelling at the rate of 300 yards per second. How infinitely small would be these particles, seeing that the most delicate optical instruments are submitted to their action for years without being injured!

If we are astonished at the extreme smallness and prodigious rapidity of the luminous molecules whose existence is necessitated by the corpuscular theory, the numerical results of the undulatory hypothesis are not less surprising. The extreme smallness of the distance between the waves, and the inconceivable quickness of their undulations, although both are easily calculated, must raise in the mind of the student feelings of the utmost wonder and admiration.

Colour, then, simply results from the difference in the rate of vibration of the rays, as Professor Tyndall observes in his lectures on the "Analogy between Sight and Sound," the impression of red being produced by waves that undulate a third less rapidly than those which produce the sensation of violet.

## CHAPTER IV.

### LUMINOUS, CALORIFIC, CHEMICAL, AND MAGNETIC PROPERTIES OF THE SPECTRUM.

The solar spectrum may be compared to a battle-field with an army drawn up upon it ready for action. In the centre we find the luminous rays, on one side the light troops which produce chemical effect, and on the other the heating rays, which may be compared to squadrons of heavy cavalry. Close by the light brigade are the magnetic rays, which are a corps of skirmishers, sometimes appearing, and at others hiding themselves from view in a very mysterious manner.

But to drop metaphor, we shall find on examination of the spectrum that the three great forces—heat, light, and chemical effect—are regularly distributed over three different portions of this wonderful band of colour.

Before Fraunhöfer the intensity of the light of different parts of the spectrum remained undetermined with any degree of accuracy; but this philosopher, by the use of a very delicate photometer, obtained the results given below.

The maximum of luminous effect is situated just at the junction of the yellow and orange. Taking this spot as its starting-point, it gradually decreases on each side until it ceases altogether at the extreme red and violet.

With respect to the calorific portion of the spectrum it was for a long time supposed that the heat-giving properties of any part were in direct proportion to the amount of its luminous effect; but Sir John Herschel proved by a long series of experiments that the heat of the spectrum gradually increased from the extreme violet to the extreme red, and that passing this point it still further increased until it attained its maximum at a point where not a single ray of light existed. From these grand experiments he adduced the important conclusion, that in solar light there existed invisible rays, which produced heat, and which possessed even a less degree of refrangibility than the extreme red rays. Sir John Herschel then tried, but unsuccessfully, to determine the exact refrangibility of the invisible heat rays.

Sir Henry Englefield compared these results, and obtained the following figures:—

| | | |
|---|---|---|
| Blue | 56 deg. | Fahr. |
| Green | 58 | " |
| Yellow | 62 | " |
| Red | 72 | " |
| Beyond the red | 79 | " |

Bérard obtained similar results, but he at first found that the maximum of heat was just at the end of the extreme red, and that beyond it the air was only about one-fifth warmer than the ordinary temperature. Sir John Herschel attributed these discordant results to Bérard having used a thermometer with too large a bulb; he accordingly repeated his experiments with other instruments with long narrow bulbs, and arrived at similar results to those obtained by the English philosopher.

We will now pass on to the physical properties of the other end of the spectrum. Towards the end of the last century, Scheele, a Swedish philosopher, remarked that chloride of silver was blackened more quickly by the violet portion of the spectrum than by any other. In 1801, Ritter of Genoa, in repeating certain experiments made by Herschel, found that a much stronger blackening effect was produced at a point beyond the violet, and that the discoloration was produced with less intensity by the violet and still less so by the blue, the change gradually decreasing till the red ray was reached. He also found that when slightly blackened chloride of silver was exposed to the effects of the red rays, or even in the space beyond, its colour was restored to it. From these facts he drew the conclusion that in the solar spectrum there existed two kinds of rays, one at the red extremity, which favoured oxygenation; the other, at the blue end, which possessed the contrary properties. He also found that when phosphorus was placed in the invisible rays beyond the red, it gave off fumes of oxide, which were immediately extinguished when it was transferred to the other end.

On repeating the experiment with chloride of silver, Lubeck found that the tint varied according to the colour in which it was placed. Beyond or in the violet ray it became brownish red, in the blue it became bluish or bluish grey, in the yellow it remained white, or became slightly yellow and reddish in or beyond the red ray. When he used prisms of flint glass, the chloride of silver was discoloured beyond the visible limits of the spectrum.

Without being aware of Ritter's experiments, Dr. Wollaston obtained the same results by acting on chloride of silver with violet light. In continuing his researches he discovered that gum guaiacum was also influenced by the chemical rays of light.

The magnetic influence supposed to be exerted by the solar rays still remains without positive proof, although numbers of philosophers have experimented in this direction. More than fifty years ago Dr. Morichini announced that the violet rays of the solar spectrum possessed the property of magnetizing steel needles that were previously free from magnetism. He produced this effect by concentrating the violet rays upon one-half of each needle with a convex lens, taking care to keep the other half concealed beneath a screen. After having continued this experiment for more than an hour, the needles were found to be quite magnetic.

Dr. Somerville tested Morichini's experiments by covering one-half of an unmagnetized needle an inch long with a piece of paper, and exposing the uncovered half to the violet rays of the spectrum, and found that the needle became magnetic in the course of a couple of hours, the exposed end being the north pole. The indigo rays produced almost the same effect, but the blue and green rays were much less powerful. When the needle was exposed to the yellow, orange, red, and invisible rays beyond the red, no magnetic effect was produced, although the experiment was continued for three days. Pieces of chronometer and watch springs were submitted to the same influences with a similar result; but when the violet rays were concentrated upon the needles and pieces of spring with a lens, the time necessary for magnetizing them was greatly reduced.

Baumgartner of Vienna and Christie of Woolwich also repeated these experiments. The latter philosopher found that when a needle of magnetized steel, copper, or even glass, vibrated by force of torsion in the rays of the sun, the arc of vibration diminished much more quickly than when the experiment was conducted in the shade. The sun's rays appeared to have the greatest effect upon the magnetized needle. From these results Christie concluded that the solar rays were capable of exerting a certain amount of magnetic influence.

These experiments were afterwards fully confirmed by those of Barlocci and Zantedeschi. The former found that a natural magnet which was capable of supporting a pound weight, had its power almost doubled by exposure to strong sunlight for four-and-twenty hours. Zantedeschi exposed a magnet which would carry fifteen ounces to the sun for three days, and increased its power two and a half times. These experiments seem almost to decide the fact of the power of white and violet light to induce magnetic force; but a series of researches by a philosopher who without doubt is greater than any of those already mentioned, seems to throw some doubt on the facts we have related above.

Before concluding, we must add a few more facts relating to the existence of invisible rays at both ends of the spectrum. "The visible portion of the spectrum," says Dr. Tyndall, in one of his Royal Institution lectures, "simply marks an interval of radiant action, the rays existing in which bear such a relation to our visual organs, as to be capable of exciting in them the sensation of light. Beyond this interval, in both directions, right and left, the radiant action continues to exercise itself, but the rays emitted are dark, in consequence of their exerting no influence on our eye. Those that exist beyond the red ray are capable of producing heat, while those that are beyond the violet excite chemical action. These invisible violet rays can be actually made perceptible to the eye, or, in other words, the undulations or waves proceeding from this end of the spectrum can be made to strike against certain substances and induce luminous vibrations, so as to connect the dark space beyond the violet with a brilliantly illuminated band. I have here a substance capable of effecting this change. The lower half of this sheet of paper has been moistened with a solution of sulphate of quinine, the other half being left in its ordinary condition. I will now hold the paper in such a manner that the line that separates the prepared half from the other shall cut the spectrum in two halves horizontally. The upper half will remain unaltered and may be readily compared with the lower half, upon which you will see the spectrum prolonged beyond its ordinary limits. The effect produced is the addition of a splendid band of fluorescent light, which extends over a space of several inches, which but an instant before was a dark mass. I withdraw the prepared paper, and the light disappears; I replace it, and the light shines forth once more; showing us in the most brilliant way that the visible limits of the ordinary spectrum are not the limits of radiant action.

" I plunge a pencil into the solution of sulphate of quinine, and I pass it over the paper. You see that wherever the solution falls, the light bursts forth. The existence of these rays has been known for a long time. Young was familiar with them, and subjected them to experiment; but it is to Professor Stokes that we are indebted for a complete series of researches on this subject. It was he who first made those invisible rays visible, as we have done."

In the same way the Professor proceeded to show that the heat rays were invisible by passing a beam of sunlight through a solution of iodine in spirits of wine, which, although it completely stopped all light, allowed the heat rays to pass uninterruptedly. By collecting these invisible rays into a focus by means of a lens, Dr. Tyndall was enabled to ignite various combustible bodies.

Thus we see the reason why certain rays produce certain effects on the eye, each particular degree of refraction causing a different set of vibrations, resulting in a different sensation for every part of the spectrum, and reproducing the effect of various colours on the optic nerve. In the following chapters we shall conclude our account of the different colours in the spectrum and of the laws of light.

## CHAPTER V.

### THE LAWS OF REFLECTION.—MIRRORS.

When a ray of light falls obliquely on any polished surface, as that of a mirror, a piece of water, a plate of burnished metal, or any other reflecting substance, the ray, like an elastic ball, is immediately projected in a contrary direction to that in which it fell. Moreover, the direction in which it is reflected is at right angles to the surface, and in the same plane as that of the ray in the first instance. This experiment may be tried very easily, and will show the reason for the two following laws.

1. The angle of incidence is equal to the angle of reflection, and *vice versâ*.

2. Reflection can only take place in one direction—in that of the incident rays, both of which are always in a plane perpendicular to the reflecting surface.

The following figure will assist the student in performing experiments on the reflection of light from flat surfaces.

The ray A B falling obliquely on the horizontal mirror, is reflected upwards at the same angle in the direction B. C. This may be proved geometrically by placing a graduated circle in a vertical position in the plane A B C, when we shall find that the angle A B D formed by A B (the incident ray) with the perpendicular D B is equal to the angle formed by this perpendicular line and the reflecting ray B C. You may also prove in the same way that these three lines are all in the same vertical plane.

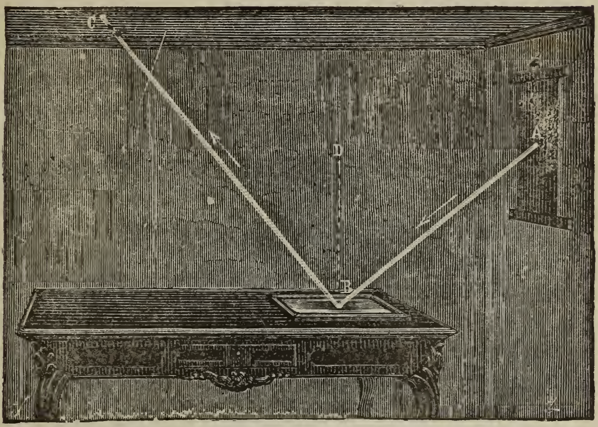

FIG. 13—Reflection from Plane Surfaces.

Let us now examine the effects of light reflected from plane surfaces. We must first, however, notice a certain optical illusion to which we are continually falling a prey, almost without our knowledge. We always fancy objects to be in reality in the place where we see them, and, in spite of our having already enumerated a large number of these deceptions, we must still add one more to the list. In reality we rarely see objects in the place where they really are; for if by the effect of reflection, refraction, or any other cause, the rays of light are made to deviate from their course, we no longer see the object from which they proceed in its real position, but in the direction taken by the luminous pencil at the moment of entering the eye.

For instance, if the ray A B is bent during its passage to the eye at B, and consequently reaches it in the direction B C, it is at A[1], and not at A, that we shall see the object from which it proceeds. Every ray of light which passes out of a medium of a certain density into

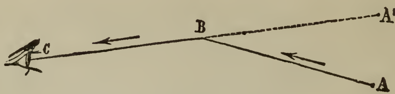


FIG. 14.—Refraction

another of a different density is bent from its primary course, or, in scientific language, it is refracted. The

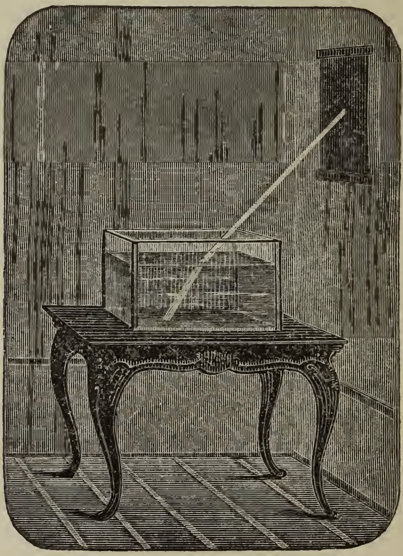

FIG. 15.—Experimental Proof of Refraction.

experiments we made in a former chapter on the properties of the prism are founded on this principle.

The law may be easily illustrated by allowing a ray of light to fall upon the surface of a vessel of water, as shown in the preceding figure.

The light of the stars and planets undergoes a similar deviation when passing in its course through the earth's atmosphere; and at the moment we see the rising of the sun, the moon, or a star, they are in reality still

FIG. 16.—The Effects of Plane Mirrors.

below the horizon. Our eyes consequently are still deceiving us, no matter what part of the domain of optics we may enter.

There are two kinds of mirrors—plane and curved. We will first examine the properties of the former sort, being those which are ordinarily applied to the usages of every-day life.

In the figure in the preceding page we have a young lady looking at her reflection in a tall cheval glass. Every point upon the surface of her clothes and face is reflected back to her eye from the surface of the tin amalgam which has been applied to the back of the mirror by the looking-glass maker, for the purpose of rendering the image of the object more brilliant than if the glass alone were used. The rays which proceed from every one of these points strike upon the surface of this metallic layer, are stopped by its opacity, and are re-

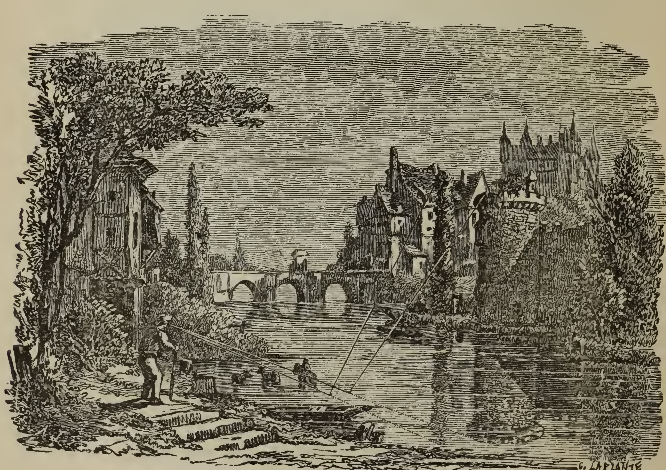


FIG. 17.—Reflection from the Surface of Water.

flected back to the eye at an angle equal to that at which they strike the surface. The image seen by the eye is formed, consequently, by the reflection of every one of these rays; and as we always see objects in the direction taken by the luminous ray at the moment it enters the eye, we fancy we see objects before us that are really behind, or on each side of us. For instance, the ray starting from the left foot of the young lady in the figure is reflected from the point indicated on the surface of the glass, but the eye does not stop here, but sees the foot at an equal distance beyond the mirror.

The same thing takes place, not only with glass, but with all substances having polished surfaces. Still water, which to all intents and purposes has a polished surface, reflects the objects within its range as perfectly as a mirror.

The preceding observations apply to all plane reflecting surfaces; but there are other sorts of mirrors, whose effects are of a more interesting nature, and which we must hasten to describe—we allude to those whose surfaces are either convex or concave.

Curved mirrors are made of a great variety of shapes, but for the present we shall only describe those which are spherical. Spherical mirrors may of course be either concave or convex.

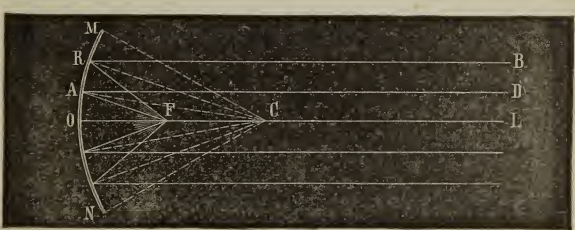


FIG. 18.—Concave Mirror.

Suppose the arc M N (fig. 18) to be movable round the point O, this revolution will describe the surface of the mirror. The central point C of the hollow sphere of which the mirror forms part, is called the centre of curvature, the line O L the principal axis. By remembering these very simple definitions, we shall be able to understand the action of these mirrors without the slightest difficulty.

To understand how the rays of light are reflected from the surface of the mirror N M at the point F, which is called the focus, we have only to consider the mirror as consisting of an infinite number of facets, all inclined towards that particular point, and forming by reason of their immense numbers a regular spherical surface. In considering the mirror from this point of view, we can immediately see that, on account of the inclination of the supposed facets, the rays that they receive are all reflected back again at the same point; and it may be proved geometrically, that when the incident rays are parallel the focus will be situated somewhere on the line O C, its position depending on the curvature of the mirror.

If, therefore, we receive on a spherical mirror a pencil of sunlight, the rays which compose it may be regarded as parallel, the sun being at so great a distance from the earth; it follows that these rays will all be reflected together in a particular point, viz., at F, and if any object be placed there it will be illuminated with great brilliancy. The laws governing the reflection of heat being nearly similar to those regulating the action of light, the rays reflected from a burning body will ignite any inflammable substance placed at the point F. The focus for parallel rays is called the principal focus of a mirror. Having described the effects of parallel rays, let us now see what happens when the source of light is close to the mirror. If it is placed at a very small distance, the luminous rays are divergent instead of parallel, and their meeting point becomes changed in accordance with the laws laid down at the beginning of this chapter. That is to say, the focus will approach more or less to the centre of curvature C, according as the source of light is placed nearer to or further from the mirror; consequently, in the case of the candle in fig. 19, instead of uniting at F, the rays will meet at *f*, a point situated somewhat nearer the mirror than the principal focus. If, instead of placing the light at A, we place it at *f*, we shall find the rays will be concentrated at the point A. Thus the foci are consequently related to each other, and are hence called *conjugate foci.* It will be readily seen that a spherical mirror may have an infinite number of conjugate foci, according to the distance of the source of light. It is also clear, that if we cause the light to approach the mirror, the focus will also approach it.

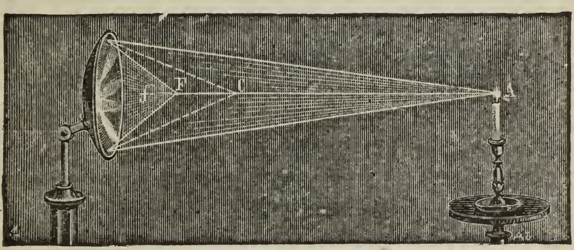


FIG. 19.—Conjugate Foci.

Continuing our experiment, we shall find that when the candle passes the principal focus so as to be between it and the mirror, the reflected rays first become parallel and then divergent, and cannot consequently produce any focus beyond the mirror, but are reflected in the way shown in fig. 20.

In experimenting on the plane mirror, we imagined we saw the object at a certain distance behind it; the same thing happens when we see ourselves reflected in a concave mirror, and the particular point at which we suppose we see our reflection is called the virtual focus.

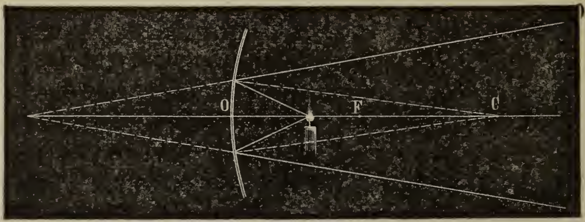


FIG. 20.—Virtual Focus.

If instead of a candle we place our head before a concave mirror, we shall see ourselves magnified as in fig. 21.

Fig. 21.—Concave Mirror.

We shall easily see how this happens by tracing the paths of the rays in fig. 22.

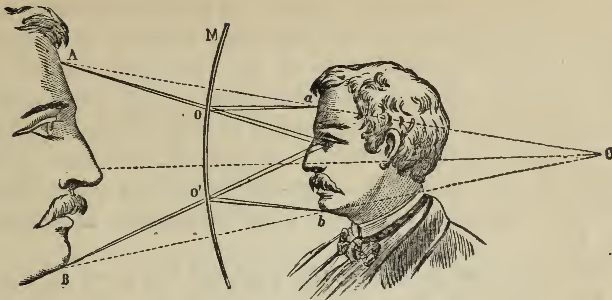


Fig. 22—Magnifying effect of Concave Mirrors

The rays, for instance, which proceed from the forehead at the point *a* are reflected from the point *o* to the

Fig. 23.—The Reversal of real Images.

eye in such a way as to appear to proceed from a point beyond the mirror, A. In the same manner the rays reflected from the chin appear to take their origin from the point B. If, on the other hand, we place ourselves at a distance from the principal focus, we shall produce a reversed and diminished image of our face. This image is not illusory, like the preceding ones, but is real, and may be received upon a screen, as shown in fig. 23.

We may easily follow the path of the rays as shown in the figure, and we shall see that the rays forming the images of the church-tower and the terrace below, cross at a certain point.

Convex mirrors produce precisely opposite effects, and give a diminished image instead of a magnified one, as may be perceived on examining fig. 24.

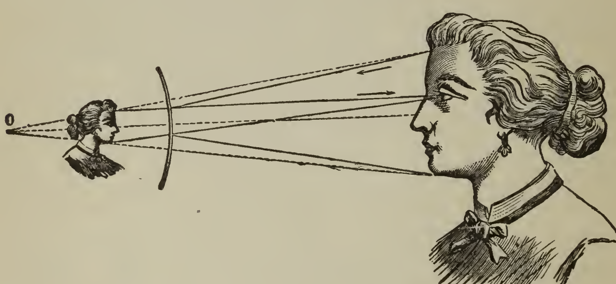


FIG. 24.—Diminishing power of Convex Mirrors.

# CHAPTER VI.

## METALLIC BURNING MIRRORS.

THE classical student will remember that Archimedes burned the fleet of Marcellus, by means of burning-glasses, from the heights of the fortifications of his native city of Syracuse. Unfortunately, any account of the system of catoptrics, or the science of reflections, employed by the ancient Syracusan in their construction is lost to us, and many modern writers have gone so far as to doubt the fact altogether. The knowledge of the properties, however, of concave mirrors which we have just been acquiring, will enable us to form a pretty good guess as to the means adopted by Archimedes for the destruction of the enemy's fleet. The ancients, not having the means of either casting or grinding such enormous mirrors, must have constructed them of a large number of small ones, so arranged that the images of the sun reflected by them would all fall in the same place, or nearly so. In this case, the larger the number of mirrors, the greater would be the burning effect. In order to explain the reflection of rays incident upon the surface of concave mirrors, we supposed them to consist of an immense number of plane mirrors placed in a curve, so that the reflected rays might all meet in one point; but on examining into the history of burning mirrors, we find that the plan has been adopted in reality in a great number of instances. We have also said, that the reflection of the heating rays was governed by similar laws to those influencing the rays of light; consequently, by directing a pencil of sunlight upon the surface of a concave mirror, we obtain the maximum of light and heat at the focal point.

Many modern writers give the ancients too little credit for their knowledge of optical principles, and late investigations seem to prove that the old school of philosophers were much more learned in these matters than has been generally supposed. The discovery of a rock crystal double convex lens in an Egyptian tomb of great antiquity is an instance of this. Descartes wrote a little treatise to prove that the stories related of the burning mirrors of Archimedes were pure fabrications, although many Latin authors have described them both as being used by that philosopher and in more modern times; Dion, for instance, who lived in the early part of the sixth century, states that at the siege of Constantinople, Proclus burnt the fleet of Vitalian with mirrors of brass; but the opinion of Descartes seemed to outweigh all other testimony. Buffon, who wished to sift the matter thoroughly, constructed for himself, after many previous experiments on the laws of reflection, a series of mirrors that closely imitated those ascribed to Archimedes. His first memoir, "On the Invention of Mirrors capable of burning at a great Distance," was published in the Transactions of the French Academy of Sciences for 1747. A few years later he combated both theoretically and practically the opinion of Descartes, in a memoir containing an account of an immense number of experiments. Before speaking of the extraordinary effects of burning mirrors, it will be as well to do justice to the predecessors of the learned naturalist we have just mentioned, by quoting a passage from the works of Father Kircher, who, 128 years previously, experimented in this direction with great patience and perseverance, and tried to prove that the stories related of Archimedes were true. "The larger the surface of a mirror," says this philosopher (who, like Huyghens, was a practised astronomer), "the more light it reflects from the objects opposite to it. If it is only a foot square, it will throw a square foot of light upon any wall or screen placed before it. Experiment shows that this light is composed of an infinite number of rays reflected from different points on the surface of the mirror. Direct the rays from a second mirror upon the same place as those from the first, and the light and heat will clearly be doubled. They will become trebled if you direct the rays from a third mirror upon the same spot, and so on *ad infinitum*. In order to prove that the intensity of the light and heat is in direct proportion to the number of reflecting surfaces employed, I took five mirrors, and found that on exposing them to the sun I obtained with only one, less heat and light than if I used direct sunlight. With two the light and heat increased considerably; three gave as much heat as an ordinary fire, and four gave me a still greater effect. I therefore concluded that by multiplying these plane mirrors, I not only obtained greater effects than those got by using parabolic, hyperbolic or elliptical mirrors, but that I could use them upon objects at a much greater distance. With five mirrors I could obtain these effects at a distance of 100 feet, but what terrible phenomena would have taken place had I used one thousand instead of five?" He ends by begging mathematicians to experiment in this direction with greater care than they had hitherto done.

After Kircher we may cite as an experimentalist with these terrible instruments the French philosopher Villette, who constructed several mirrors, in direct imitation of those of Archimedes, for Louis XIV. and other sovereigns. The *Journal des Savants* for 1679 gives an account of his principal metallic burning mirror in the most eulogistic terms, adding an instance of ignorance which is singularly quaint and curious. It is of the fourth and most perfect of Villette's mirrors that the *Journal des Savants* speaks, the first having been bought by Tavernier, and presented to the Shah of Persia, who considered it as one of the rarest and most precious curiosities that he possessed: the second was sold to the King of Denmark, and the third was given by M. Villette to Louis XIV., from whom he received the praises and rewards that were due to his talent and perseverance. "It was thirty-four inches in diameter, and vitrified flints and bricks almost instantaneously, no matter how large they were. It consumed the greenest wood, burning it to ashes in an instant, and fused the most refractory metals with equal ease and quickness. Steel, no matter how hard, resisted its power no more than other metals, and melted so quickly that one part burnt away in inconceivably brilliant sparks, some of them forming stars as large as a franc piece, leaving a flowing mass of metal behind. The last made by Villette was still more powerful, being larger and more carefully made. It was forty-four inches in diameter, and three inches and a line deep. Its burning point, or focus, was situated at a distance of three feet seven inches from the surface, and was apparently as large as a five-sou piece; and it was at this spot, where the rays of light and heat were concentrated into so small a space, that the wonderful effects of its violent power became manifest, the spot of light being of such brilliancy that the eyes could no more withstand its brightness than that of the sun. Besides the property of burning which it possessed in so wonderful a degree, it was capable of exhibiting other effects just as curious as those already related. It had the power of sending the images of objects to a distance of fifteen feet or more, so that a man looking at himself in this mirror with a stick or sword in his hand, saw the image of them suspended in the air, apparently ready to strike the observer. On seeing such an effect for the first time, the observer could hardly fail to experience the greatest surprise, and even fear; and it is stated that the king having placed himself, sword in hand, before one of these mirrors, in order to observe the effect, was surprised to find himself face to face with an armed hand apparently directed against him. When he advanced, the hand seemed to spring forward to meet him. The king could not conceal his surprise and fright, and afterwards felt so ashamed at being terrified with a mere shadow that he ordered the mirror to be taken away, and could never be prevailed upon to look into it again." The *Journal des Savants* then goes on quaintly to remark on the various startling effects produced by these mirrors, winding up by stating that its powers of reflection were so great, that at night the light of a torch or flambeau was reflected so perfectly that an observer placed at four hundred feet distant could read the smallest print.

It also mentions a curious piece of superstition on the authority of a scientific writer of the name of Robertson, who states that it happened at Liége. In reading the accounts of these experiments we can see how easily the minds of individuals were affected in those days by the wonderful. It happened while one of Villette's mirrors was at Liége, that the latter end of the summer was somewhat rainy, and great fears were entertained that a bad harvest and dear bread would be the result. Certain evil-minded people, who had taken a fancy to the mirror and wished to possess it by unfair means, spread the report that the continual rain was entirely caused by its action on the clouds and sun, and that the coming famine must be laid upon the shoulders of its owner and inventor. This absurd idea took such forcible possession of the minds of the populace of Liége, that great mobs collected together, uttering all kinds of maledictions against the mirror and its inventor, and at last became so violent that they attacked Villette's house with the intention of smashing his great work, and administering to the unfortunate philosopher the chastisement they supposed he deserved. Happily, however, for M. Villette and his mirror, Liége was governed in those days by the Prince Bishop of Cologne, who was a man of great enlightenment. He put the crowds round M. Villette's to flight by armed force, but he found that the conviction that all the coming mischief would result from the unlucky mirror was so strong, that he was obliged to issue a pastoral peremptorily declaring that the idea had originated with a number of malicious people, who spared no pains to propagate it for their own bad purposes, and that it was a mischievous and dangerous error to ascribe to a mirror a power which only belonged to the Almighty.

In 1747, Buffon performed many extraordinary experiments with burning mirrors, which were more surprising than any that had hitherto been described. They were mostly performed at the *Jardin des Plantes*, at Paris, of which institution Buffon was director; and many of them are worth describing.

On the 3rd of April, at about two o'clock in the afternoon, the great mirror was mounted on its stand, and was found to be capable of setting a plank of wood on fire at a distance of 138 feet, when 128 glasses were used, although the light was weak at the time, and the sun was covered with mist. In pursuing these experiments great care had to be taken to prevent the bystanders placing themselves within range of its terrible power, for several were nearly blinded by looking

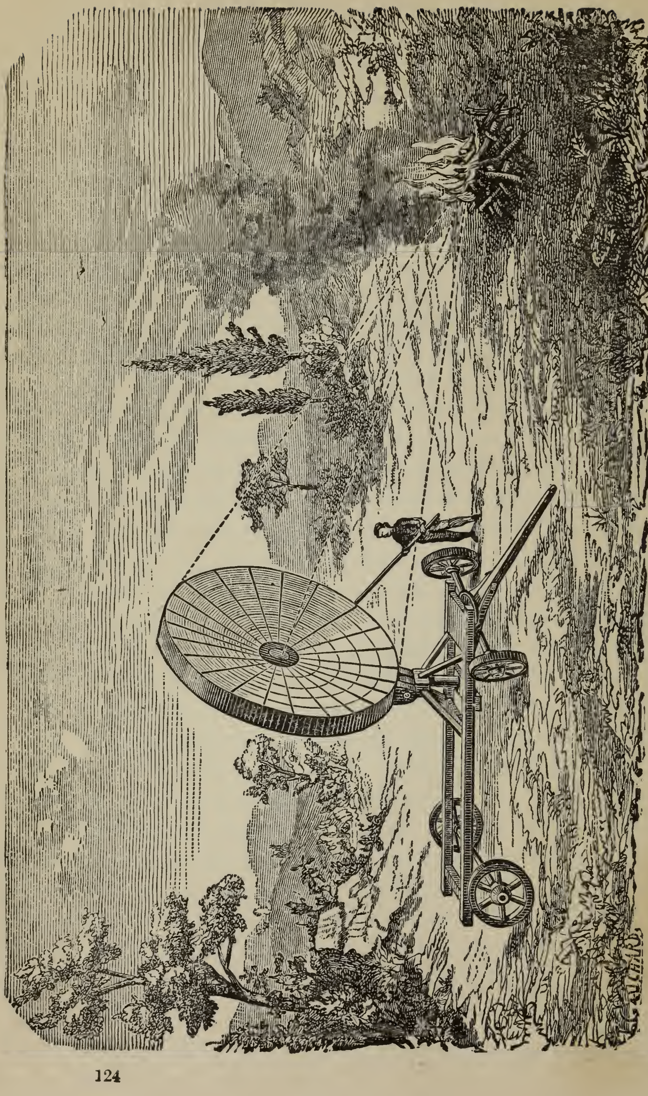

Fig. 25.—Burning Mirror.

at the brilliant focal point of the instrument. The next day, at eleven in the forenoon, although the sun was still covered with mist and fleecy clouds they were able to produce such a heat at 150 feet distant, with 154 glasses, that a pitched plank began to smoulder and would have burnt into flame had not the sun disappeared at that particular moment. On the fifth of April, at three in the afternoon, with the light much in the same weak condition as it was on the other days, they succeeded in igniting at 150 feet distant, a heap of shavings of deal mixed with charcoal and sulphur, in less than a minute and a half, with 154 glasses. When, however, the sun shone with its natural power, a few seconds were sufficient to effect these results.

On the 10th, when the sun was shining pretty powerfully, a pitched pine plank was easily fired with 128 glasses, at 150 feet distant. In this case the ignition was very sudden, and extended over the whole of the radiant spot forming the focus, which at the distance named measured 16 inches in diameter. The same day at half-past two, a pitched elm plank covered in some places with chopped wood, was set fire to with extreme rapidity, and burnt with such violence that it had to be dipped in water before it could be put out. In this experiment 148 glasses were used, at a distance of 150 feet.

On the 11th of April, the burning point was fixed at 20 feet distant from the mirror, and combustible substances were easily burnt with only 12 glasses. With 21 glasses a half-burnt elm plank was set fire to, and with 45 a piece of tin weighing six pounds was almost immediately melted. Silver sheet was fused, and an iron plate was made red-hot with 117 glasses. In giving an account of these interesting experiments, Buffon expresses his conviction that at 50 feet it would have been easy to have melted metals if all the glasses of the mirrors had been used. When used at that distance, the burning spot was six to seven inches in diameter. He also noticed that when metals were melted, part of them were dissipated in brilliant vapour, which was so thick as to cast a shadow on the ground, although it seemed to be as bright as the sun itself. When the sun was at its full strength, and all the glasses were brought into requisition, wood was set on fire at a distance of over 200 feet, and metals and minerals were fused at 40 and 50 feet. Hence the possibility of making and using these mirrors as Archimedes was said to have done, was proved practically by the great naturalist. Fig. 25 represents a burning mirror in action.

Robertson, an English philosopher, residing in France during the days of the first Republic, reconstructed the mirrors described by historians as being used by Archimedes, and the results he obtained were thought sufficiently important by the Council of the Department of Ourthe to merit an attentive examination by two members of their body, who reported in favour of their being used as instruments of war.

It would be possible to pursue this subject still further, and give an account of numerous experiments made on burning mirrors by various philosophers, but we must not forget that it is light and heat that we have more especially to deal with in the present work. Already we have possibly strayed from our path a little too far, but the two influences are so closely connected with each other that it is almost impossible to speak of them separately when reflection is in question.

# CHAPTER VII.

## LENSES.

THE word lens is derived from the Latin name of the seed of the *Ervum lens*, or ordinary lentil. When eating this wholesome vegetable, almost every one has noticed that its shape is exactly that of a double convex lens, as represented in the following figure:—

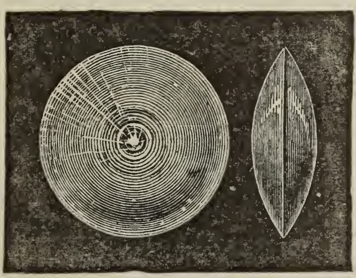

FIG. 26.—Double Convex Lens.

Perhaps it would be more correct if we were to say that a double convex lens is like a lentil, rather than turn the comparison the other way, seeing that this little seed has given its name not only to the particular-shaped glass depicted above, but also to some five others more or less analogous to it.

In fig. 27 we have the different forms of lenses shown in section. The first is the *double convex lens*, the second the *plano-convex*, the third and sixth the *concavo-convex*, the fourth the *double concave*, and the

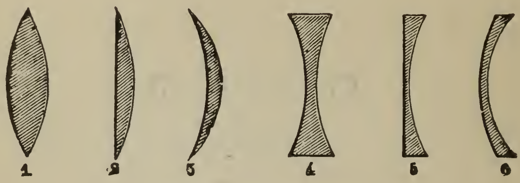

FIG. 27.—Forms of Lenses.

fifth the *plano-concave*. A *crossed lens* is a double convex lens whose one side is more convex than the other. The third lens is also called *meniscus*.

The properties of the first, second, and third are similar; that is to say, they cause parallel rays of light passing through them to converge at a certain point, called their focus; while the three others have a divergent action on rays passing through them. By examining the path of the rays through these lenses, we shall find that the first three magnify objects seen through them, while the latter have the contrary effect.

As in the case of the curved mirrors, the rays falling on the surface of a convex lens may be either parallel, divergent, or convergent. In the case of parallel rays, as depicted in the following figure, they are represented as meeting at a point beyond the lens, which is called the sidereal focus, or the focus for parallel rays. It is generally found by causing the image of the sun or of some distant object to be thrown by the lens upon a screen, or by knowing the curvature of the faces, and the refractive power of the glass.

Every ray on striking the surface of the lens is refracted inwards, until it meets with its companions at the focus F, in accordance with the law of refraction, by which a ray of light passing from one transparent medium, such as air, to another which in this instance is glass, becomes refracted or bent in proportion to the

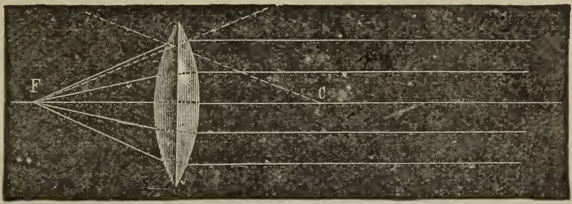


FIG. 28.—Path of a Ray through a Convex Lens.

relative density of the two mediæ. The nearer the ray passes to the edge of the lens, the more it is refracted, the angle of incidence being greater; the ray through the exact centre being uninfluenced by the form of the glass. Hence they all meet in a single point. Figs. 29 and 30 show the path of the rays when they are divergent and convergent.

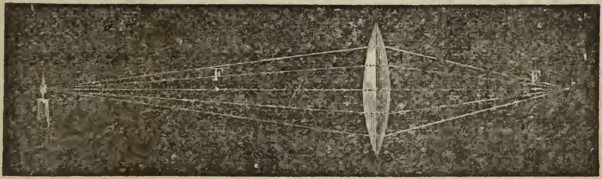


FIG. 29.—Path of divergent Rays through a Convex Lens.

If the rays of light are not parallel, as in the case of the source of light being near the lens, they do not converge so rapidly as when they proceed from a distant object, consequently the focus for near objects is longer in proportion to their distance. In fig. 29 for instance, if a candle be placed as shown, and a screen on the other side of the lens, a point will be found where the image of the candle is seen upon it in a reversed position. The distance between these two points is always relative, and they are called conjugate foci. Thus, the candle may change places with the screen with a similar effect, as long as the exact position of the two points is preserved. If the candle is placed

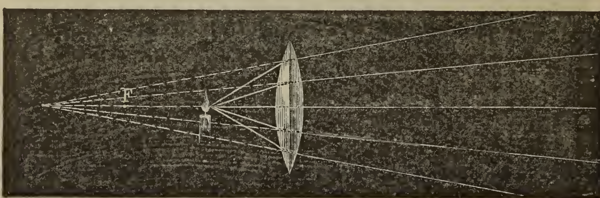


FIG. 30.—Conjugate Foci.

farther off, we must diminish the distance between the screen and the lens, and *vice versâ*. In fact, the nearer the object, the longer the focus; the farther it is off, the shorter the focus. Half an hour's experiment with a double convex lens, a piece of white card-board, and a small candle, will teach the student more about the properties of convex lenses than a chapter of explanation. A common magnifying glass, or even an old spectacle lens, will serve the purpose of more expensive instruments.

We now proceed to speak of the images formed by lenses. In fig. 31 we have a flower placed on one side of a lens. As it is not at an infinite distance, the rays sent out by its various parts are convergent, and not parallel, consequently they do not meet at the sidereal focus, but at a point beyond it, according to the rule already laid down. The rays proceeding from the exact centre of the flower striking the lens exactly in the middle at right angles, suffer no change, the others being refracted in proportion to their angles of incidence.

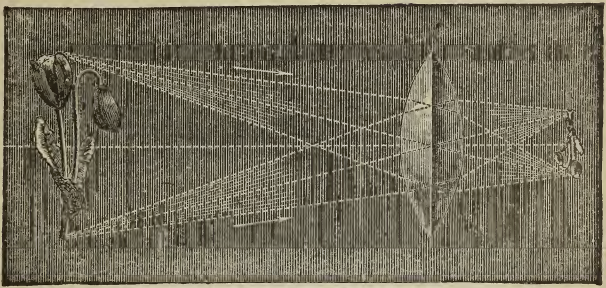

FIG. 31.—Images formed by Convex Lenses.

The rays proceeding from the flower cross each other at a certain point: hence the image on the screen is reversed. The dimensions of the image will depend on the distance of the object from the lens. This is a fact we meet with every day, when using an opera-glass or a telescope. Images formed by convex lenses upon a screen are called by opticians *real images*, in contradistinction to those which are the result of mere reflection, as in the case of plane mirrors. These latter are known as *virtual images* and are produced by convex lenses as well as by plain reflecting surfaces. In fig. 32, for instance, the unreversed image of the insect seen by the eye is not a real image, but a virtual one,—a fact that might be easily proved by placing a screen in the position of the eye, when it would be found that no image would be formed.

When using an ordinary magnifying-glass we see the virtual image of the object we are looking at, but in the case of a telescope or opera-glass we see the real image of the object, formed by the large lens in front, and reversed again by the arrangement of small lenses next to the eye.

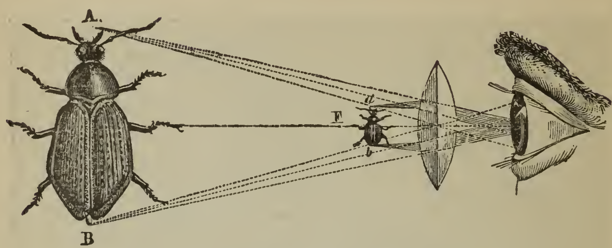


FIG. 32.—Magnifying Property of Convex Lenses.

Double concave lenses produce effects which are just the reverse of those we have been considering. Instead of increasing in thickness from the edges to the centre, they follow the contrary plan, and increase from the centre to the edges. Consequently, instead of the rays meeting at the focus, they diverge from each other, and gradually spread out, as shown in fig. 33.

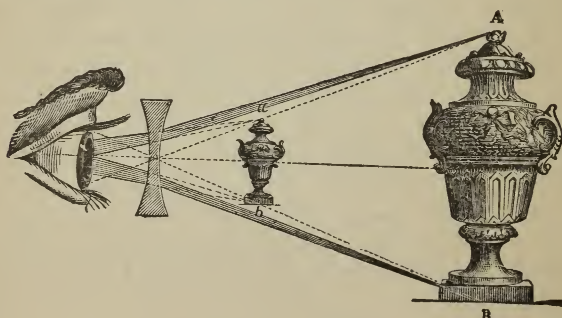


FIG. 33.—Diminishing Effect of Concave Lenses

The above figure shows the path of the rays proceeding from the vase, and meeting the eye at such an angle

Fig. 34.—Cannon of the Palais Royal.

that the virtual image is greatly diminished. Concave lenses, as the student has no doubt already guessed, do not give real images.

The effects produced by the action of concave mirrors may be produced with just as much facility by convex lenses. If a body is placed in a focus of a lens which receives the direct rays of the sun, the heat as well as the light will be concentrated at one point; and if the object is combustible, it will take fire sooner or later, according to the size of the lens. All the experiments mentioned by Buffon as being produced by a concave mirror are equally obtainable with a concave lens. When of sufficient diameter, the most refractory metals, such as platinum or iridium, may be melted and dissipated into vapour. Before lucifer matches and vesuvians were as common as they are now, it was not at all unusual to find smokers carrying a small burning-glass and a piece of tinder, for the purpose of lighting their pipes or cigars; and there hardly exists a boy who has not lighted a bonfire in the fields or playground by means of an old spectacle lens or telescope glass.

Amongst other applications of this property of lenses may be mentioned that of causing guns to fire at a certain time, by arranging a small burning-glass above the touch-hole. In the Gardens of the Palais Royal, at Paris, there is such a gun, so arranged that on sunny days it fires exactly at noon, or, in other words, at the moment the sun comes to the meridian. Every fine day towards twelve o'clock, crowds of Parisians who have nothing to do may be seen bending their steps towards the Palais Royal to set their watches by the gun, which they believe to be superior as a time-keeper to the finest chronometer in the world. There they stand. most of them old fellows with a scar or two about their faces, showing that they have nobly won the rest they appear to enjoy so innocently and calmly with watch in hand, leaning against the railings, and waiting with impatience the moment when true solar noon is indicated by the sharp report of the little piece. Their belief in the correctness of solar time is something astonishing; and if a bystander were to insinuate, no matter how delicately, that solar time varied slightly every now and then, he would either receive a smile of pitying contempt, or else he would be called out upon the spot. Fig. 34 gives a pretty view of the celebrated cannon of the Palais Royal.

We now come to another application of the refracting power of lenses, in the way of concentrating rays, which is infinitely more valuable to humanity than

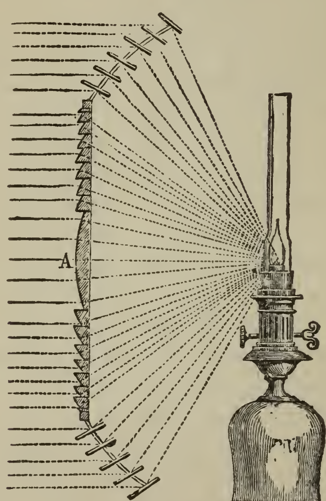


Fig. 35.—Fresnel's Lighthouse Apparatus.

either of those we have just mentioned; we mean the construction of enormous refracting apparatuses for lighthouse purposes. The first lighthouse of which we have any record is that which was erected on the island of Pharos, by Ptolemy Philadelphus, in the year 470 of the foundation of Rome. This was merely a tower, upon the top of which fires were kept burning at night; but as the world progressed, the blazing tar-barrel or wood fire gave place to the carefully-constructed lamp and silvered reflector apparatus, which are fast disappearing in their turn before the electric or Drummond light and the refracting apparatus constructed by Fresnel, who was the first to endeavour to abolish the old-fashioned and inefficient metallic mirror from the lanterns of lighthouses. Fig. 35 shows a section of Fresnel's apparatus. A is a plano-convex lens of about a foot in diameter, whose focus corresponds with those of the concentric lenticular rings of glass which surround it, and which are seen more plainly in fig. 36. These rings, which are ground and polished with the greatest accuracy, are somewhat in the shape of an ordinary quoit, and are equivalent to a plano-convex lens with the centre portion cut out. This arrangement is so powerful that the distance at which a light provided with it can be seen is only limited by bad weather, the state of the atmosphere and the distance of the horizon. It is common for such lights to be seen at a distance of between fifty and sixty miles. The apparatus is mostly arranged in the form of an octagon, and is generally provided with additional reflecting mirrors at those parts above the light which are out of the range of the lenses. The light shining fully in eight directions at one time, can scarcely be missed by any ship within range; but in order to guard against any possibility of accident, the optical apparatus is often made to revolve by clockwork, so that every point of the ocean is illuminated in turn. By using coloured glasses, or by causing the light to disappear at distinct intervals, different lighthouses may be identified by ships that are out of their reckoning. Fig. 36 represents the interior of the lantern of a first class lighthouse, showing the arrangement of the lenticular rings round the central lens. If ever the student should pass through Havre, he should not miss the opportunity of seeing this noble apparatus, which is one of the finest ever manufactured.

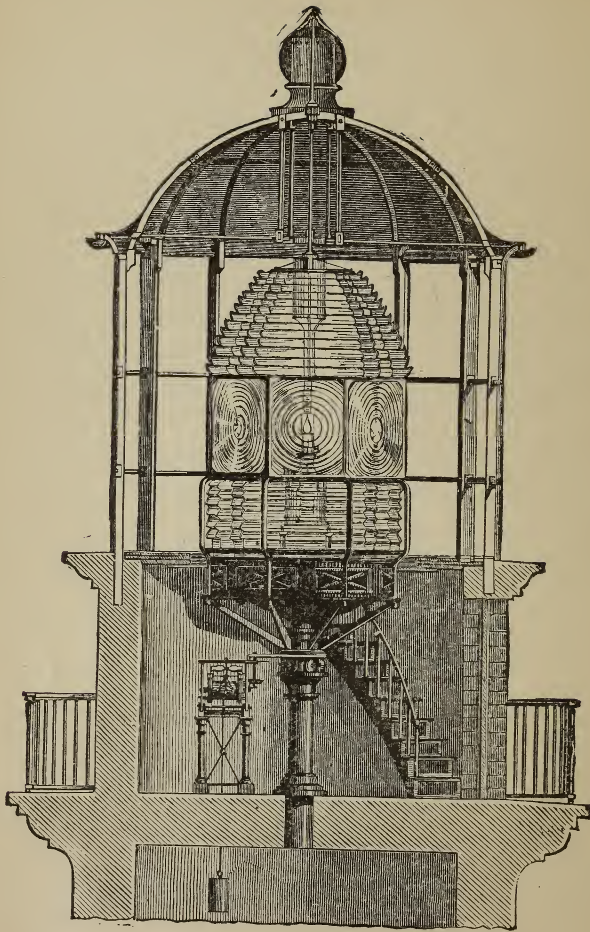

FIG. 36.—Lantern of a First-class Lighthouse.

# CHAPTER VIII.

OPTICAL INSTRUMENTS.—THE SIMPLE AND COMPOUND MICROSCOPE. THE SOLAR AND PHOTO-ELECTRIC MICROSCOPE.

THE lenses and mirrors whose properties we have been considering in the previous chapters, have been combined in different ways for the purpose of examining objects too small or too distant to be perceived by the human eye. To instruments used for the former purpose the name of microscope has been given, from two Greek words signifying *small* and *to see*. In like manner the name of telescope is also derived from two Greek words, meaning *distant* and *to see*. Besides these two classes of optical instruments, others have been devised to facilitate the depicting of natural objects, either by means of the pencil or of photography, or to amuse the eye by optical illusions. Thus we have the camera obscura, the camera lucida, the magic lantern, the phantasmagoria, and numberless other instruments of the same sort, most of which will be described in the latter part of this book.

There are two sorts of microscopes, the simple and the compound; the one consisting of a single convex lens, and the other of several combinations of both convex and concave lenses.

When speaking of convex lenses, we described the properties of the ordinary magnifying glass, or simple microscope. The uses of this instrument are almost too well known to need description. It is used by old people, the lenses of whose eyes have become flattened by old age, by watchmakers for examining the minute portions of their work, by jewellers for the same purpose, and by most people for examining maps, engravings, and photographs. Simple microscopes are generally mounted in horn, ivory, or metal handles for convenience' sake. Some simple microscopes consist of two or more lenses mounted together in order to increase the magnifying power. The student must distinguish between several lenses mounted together in this way, and the true compound microscope, which is a comparatively complicated optical arrangement, as we shall see presently. When two single lenses are thus mounted together, the power of the combination is equal to the powers of each added together.

There is good reason for supposing that the simple microscope is a comparatively ancient invention. Seneca, who lived in the first century, declares that in his time it was well known that, when writing was looked at through a globe full of water, it appeared larger and blacker. In the eighth century we find the use of magnifying spectacles for old people common in most countries, and yet it was only at the beginning of the seventeenth century that a true optical instrument, in the form of a telescope, was invented. It only needed the placing of two magnifying glasses in a line to discover the principle of the telescope, but nearly a thousand years elapsed after the first introduction of these glasses before an accident rendered the principle evident.

In fig. 37 we see the commonest form of microscope in the hands of an observer; and by examining the following figure and tracing out the path of the rays, we shall easily discover the principles on which its action depends.

The object to be looked at is placed at *a* (fig. 38), on a piece of thin glass usually called a *slide*. A small

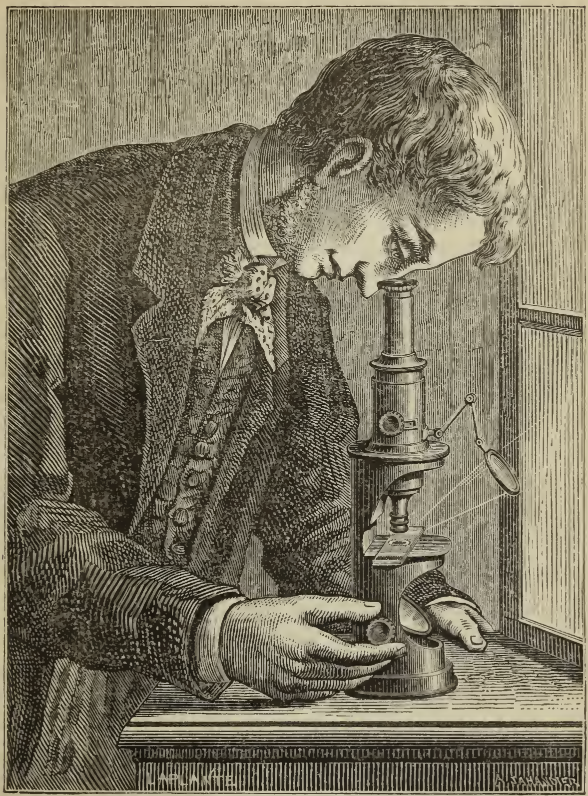

FIG. 37.—The Compound Microscope.

converging lens placed at *b* collects the rays proceeding from the object, and transmits them as far as *c d*, where they come under the influence of a second converging lens B, which causes them to spread out still more before they reach the eye. Consequently we not only see the image of the object magnified by the lens *b*, but still more enlarged by the action of the lens B, and appearing considerably enlarged at C D. The lens placed in front of the object is called the *objective* or *object-glass*; that placed nearest the eye, the *eye-piece*. These names apply equally to the similar lenses used in telescopes and other optical instruments. The instrument shown in fig. 38 is the simplest possible compound microscope, and is very rarely used. The eye-piece is generally constructed of two lenses, and the object-glass of as many as eight; the object in multiplying the lenses being, not only to increase the magnifying power, but to decrease certain defects inherent in all lenses whose surfaces are parts of spheres.

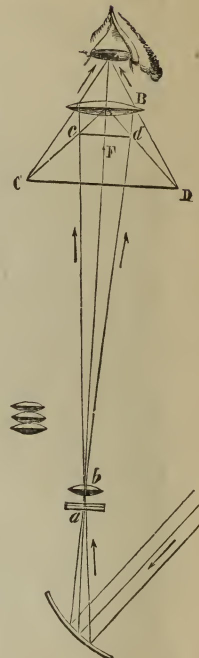

FIG. 38.—The Theory of the Compound Microscope.

The amplification depends mainly upon the power of the objective, but different eye-pieces are also used to increase the apparent size of the objects to be examined. Thanks to the investigations of modern philosophers, we are enabled to magnify objects to 2,000 times their diameter with perfect distinctness; that is to say, the surface of the object appears to occupy 4,000,000 times its natural extent. Under such a power a hair would appear about six inches thick, a fine needle would look like a street post, and a grain of sand like a mass of rock. Although it is possible to employ compound microscopes of such a high magnifying power in the investigation of certain classes of objects, all ordinary preparations are best seen under a power of 500 or 600 diameters. It would be utterly impossible to give our readers the slightest idea of the benefits conferred on the human race by this marvellous instrument. Suffice it to say, that no naturalist or surgeon ever attempts the most simple investigation into the structure of any body without the aid of the microscope. It has already shown us that a world of creatures exists which, although invisible to the eye of man, are possessed of wonderful forms, colour, and beauty of structure, and is daily adding to our knowledge in this direction. We can hardly submit any substances to this marvellous instrument without discovering animal or vegetable life of the most vivid character. A drop of scum from the surface of a stagnant pool is instantly seen to be peopled with animal and vegetable life, when submitted to microscopic examination. At one moment a rolling ball glistening like glass slowly revolves past our view; then a little fellow like a piece of spiral spring screws his way along, backing when he meets with an obstacle; or a shuttle-shaped vegetable, apparently made of glass, with green balls inside him, slowly works his way from side to side, or, possibly, a mad battledore-shaped being dashes past at an inconceivable rate.

As it is indispensable that the object should be well lighted, a concave mirror is placed below it to reflect the rays of light from a lamp or white cloud, through the object when it is transparent. When it is opaque, it is illuminated by the rays of light being concentrated upon it by means of a convex lens. The name microscope appears by common consent to be applied more particularly to the compound instrument, the epithet of magnifier or magnifying-glass being kept for simple microscopes, although they are all, strictly speaking, *microscopes*.

In the ordinary compound microscope, it is only possible for one person to see the object to be examined at once; for popular exhibitions of microscopic objects the reflecting microscope has been devised, by means of which the images of the objects to be looked at are thrown upon a screen. The principle of this instrument is the same as that of the magic lantern and phantasmagoria, of which we shall speak presently. Fig. 39 (see next page) represents the photo-electric microscope, so called from the objects being reflected by the electric light.

The jars seen on the ground are the cells of a voltaic battery, by which the electricity is generated. The luminous rays starting from the incandescent charcoal points are reflected through the tube and its lenses by the reflector placed at the back of the instrument, and are concentrated upon the object to be magnified. The image thus produced passes through a second system of converging lenses, and is projected upon the screen magnified some millions of times according to the power of the object-glass employed.

"The experiments made with the photo-electric microscopes," says M. Ganot, "are amongst the most curious and pleasing to be found in the whole range of physical science. With this instrument it is possible to show the smallest objects magnified almost indefinitely to an unlimited number of spectators. A human hair will appear as large as a broomstick, an ordinary flea will look the size of a sheep, and the tiny cheese mite, as well as the smallest animalcules, will be visible in all their beauty of form and colour as clearly as if they were seen with the naked eye. One of the most remarkable experiments to be made with this instrument is that which shows the circulation of the blood. The tail of a live tadpole is inserted between two plates of glass, or on an instrument specially made for the purpose, and placed in the microscope armed with a somewhat low power. The

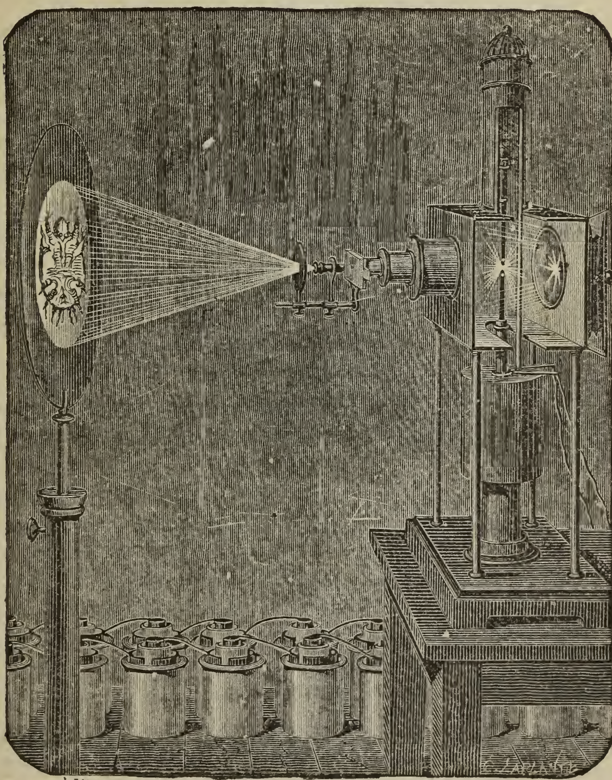

Fig. 39 —Photo Electric Microscope.

spectator immediately perceives upon the screen a mass of rivers and rivulets, all flowing with the red corpuscles forming the blood of the animal, and rushing through its veins and arteries with inconceivable rapidity. Another interesting experiment consists in dissolving a small quantity of sal-ammoniac in warm water, and passing a small portion of the solution across a warm glass slide. When placed in the microscope the water gradually evaporates, leaving behind a mass of feathery crystals, whose growth may be watched atom by atom, each crystalline molecule grouping itself around the others in forms resembling a mass of fern-leaves."

The apparatus we have been describing is sometimes illuminated with the rays of the sun, as in the following figure.

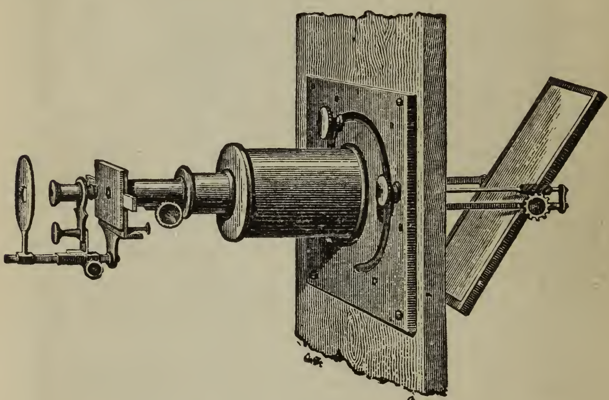

FIG. 40.—Solar Microscope.

It is then called the solar microscope, and exhibits objects with great beauty and clearness. The use of the sun's rays, however, has, in our own country at least, been entirely superseded by the electric and lime light. The latter method of illumination, which consists in projecting a stream of oxygen and hydrogen upon a ball of lime, is cheaper and more certain than the electric light, although the latter is possibly the more brilliant of the two. The construction of the solar microscope differs but little from the instrument already described, and may be readily understood from the foregoing figure. The large mirror is placed outside the window of the room in which the microscope stands, so that the solar rays are reflected upon the surface of a series of convergent lenses, and from thence on to another mirror, from which it is again reflected through the microscope. As the position of the sun is constantly changing, it is necessary to connect the outside mirror with a train of clockwork. It may be mentioned that an instrument of this kind, for reflecting the sun's rays, is called a heliostat.

The student will, no doubt, at once perceive that if we concentrate the light of the sun upon an object, we shall also concentrate the heat, and either melt or consume it. A screen is therefore used in such cases, which will allow the light to pass while holding back the rays of heat. A solution of alum is found to answer the purpose admirably.

## CHAPTER IX.

### THE TELESCOPES OF GALILEO, GREGORY, NEWTON, HERSCHEL, LORD ROSSE, AND FOUCAULT.

If history has failed to furnish us with the name of the inventor of the microscope, we have very exact information as to the first experimenters upon the powers of the telescope.

"In the archives of the Hague," says Arago, "we find documents, by the aid of which Van Swieten and Moll have come to a decisive conclusion as to the first and true inventor of the telescope."

We read in these documents that a spectacle-maker of Middleburg, named John Lippershey, addressed a petition to the States-General on October 2, 1606, in which he asked leave to take out a patent, which should constitute him the only maker of this instrument, or which should confer upon him an annual pension, on the condition of not manufacturing them for other nations. The petition qualifies the instrument as serving to see distinct objects, as had already been explained to the members of the States-General.

On the 4th of October, 1608, the States-General appointed a deputy from each province to experiment on the new instrument, which was placed on a tower of the palace belonging to the Stadtholder. Huggard says that the first telescopes experimented on were a foot and a half in length.

On the 6th of October, the commission declared the instrument of Lippershey to be useful to the nation, but demanded that it should be made for two eyes instead of one.

On the 9th of December, Lippershey, having announced that he had solved the problem, Van Dorth, Magnus, and Van der Au were ordered to verify the fact, which they did by making a very favourable report on the 11th of the same month. The binocular instrument was therefore found to answer.

In reading the extracts from the archives of the Hague, given by Moll, we may remark with great pleasure the promptitude with which the commissioners of the States-General examined Lippershey's instruments. But their satisfaction soon gave way to displeasure, when they found a large number of opticians making these instruments, and selling them to foreigners, like so much spice from the East Indies. Later on one feels indignant at finding the commissioners of the States-General to be so wanting in proper feeling as to decide that the telescope must be considered imperfect until it could be used with both eyes, without either winking or seeing the reflection of the pupils in the eye-pieces. Consequently, instead of being permitted to expend his talent on perfecting the optical powers of the single telescope, Lippershey saw himself condemned to waste his time upon the double instrument. The States-General finished by giving Lippershey 900 florins; but they refused him a patent, on the ground that it was already notorious that other opticians had commenced the manufacture of similar instruments.

Amongst others who were rivals of Lippershey, we must mention John Adrian Metius, the son of Adrian Metius, of Amsterdam, who discovered that the nearest relation of the circumference of a circle to its diameter was 355 to 113. He addressed a letter to the States-

General on the 17th of October, 1608, conceived in the following terms :—

"After two years' labour and thought I have succeeded in making an instrument, by the aid of which objects which are too distant to be visible by the eye, are seen plainly. The one I show, although constructed out of bad materials, and simply as an experiment, is, in the judgment of the Stadtholder and of several other persons, as good as the one lately presented to the States-General by a citizen of Middleburg. I am sure of improving it still further in the course of time, and I beg to ask for a patent by which any person who is not already in possession of this invention will be forbidden, under pain of a heavy fine and confiscation, to make or sell similar instruments for twenty-two years."

The States-General refused to grant the patent in this case also, but enjoined Metius to perfect his instrument, reserving to themselves the power to reward him in the future if they thought fit.

In Italy, Galileo is generally supposed to have discovered independently the method of making a telescope on the principle of the Dutch philosophers, about the beginning of 1609, having received a very imperfect account of these instruments somewhere about that time. It may be remarked that in his letter to the chiefs of the Venetian Republic, giving an account of the properties of these new instruments, Galileo states that, if necessary, they could be made specially for the use of the navy and army belonging to the state. But secrecy was useless, for telescopes were already made and sold in Holland at a cheap rate. Besides, Galileo makes no allusion to the labours of his Dutch predecessors, either in a prior letter handed down to us by Venturi, or in the decree of the Venetian Senate, dated August 5, 1609.

The Italian commentators are in error when they attribute the second discovery of the telescope to the knowledge that Galileo possessed of the laws of refraction, and that it was by deductions therefrom that he was enabled to construct his first instruments.

Huyghens says, in his *Treatise on Dioptrics*, "I will unhesitatingly place that man above all mortals, who, by the aid of his own reflections and without the aid of accident, first succeeded in constructing a telescope."

"Let us see," says Arago, when speaking on this subject, "if Lippershey and John Adrian Metius were men of unparalleled powers."

Hieronymus Saturnus tells us that an unknown man of genius called upon Lippershey, and ordered from him a number of convex and concave lenses. At the time agreed upon the man returned, and chose two, one convex and the other concave, and, placing them one before his eye and the other at some distance from it, drew them backwards and forwards, without giving any explanation of his manœuvres, paid the optician, and left the place. As soon as he was gone, Lippershey began immediately to imitate the experiments of the stranger, and soon found that distant objects were brought apparently nearer, when the lenses were placed in certain positions. He next fastened them to the ends of a tube, and lost no time in presenting the new instrument to Prince Maurice of Nassau.

According to another version, Lippershey's children were playing in their father's shop, and were looking through two lenses, one convex and the other concave, when they found to their surprise that the vane on the clock-tower of Middleburg Church was greatly magnified and apparently brought nearer. The surprise expressed by the children having awakened the attention of Lippershey, he tried the experiment of fixing the lenses on a piece of board; afterwards he tried it again by fixing them at the ends of two pieces of tube, sliding in each other, and succeeded in making the first telescope on record.

The principal documents from which the above facts touching Lippershey have been extracted, are to be found in a memoir on the subject by Olbers, printed in Schumacher's *Astronomical Annual* for 1843.

It was said in the time of Galileo that he had in his possession a telescope by the aid of which he could see the birds flying at Fiesole from the window of his palace in Florence. This story does not in the least detract from the merit of the illustrious astronomer, who not only constructed a telescope for himself, but was the first to direct it heavenwards, and that too by purely theoretical researches; for in spite of all the documents adduced above, there is little or no proof that he had ever seen or heard of the Dutchman's telescope. It is only right, therefore, that the instrument constructed on this principle should be called the Galilean telescope. He afterwards increased its power from four to thirty times, beyond which he could not get with the means at his command. With his imperfect instruments Galileo discovered the satellites of Jupiter, the mountains of the moon, and the spots on the sun, and earned for himself the name of Lynceus, who according to the ancients was one of the Argonauts, possessed of the power of seeing through a wall. Towards the end of his life, when the old man was blind, and the Academy of the Lincei treated his hypotheses with disdain, he would laugh sadly at the name bestowed on him, and the obstinate Academy. Fig. 41 (see next page) shows the path of the rays in a Galilean telescope. The object-glass *o* is double convex, and the eye-piece o biconcave. The image is formed between these lenses, and the eye appears to see it at that point. The States-General complained of being obliged to shut one eye when looking through a telescope, but in 1671 a good

Capuchin monk, whose name was Cherubino, placed two telescopes together, little thinking that the moderns

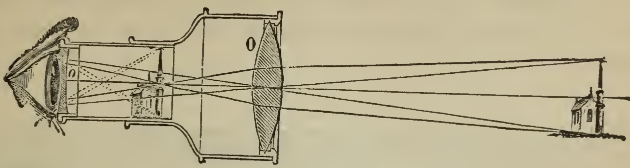


Fig. 41.—The Galilean Telescope.

would imitate him in that very worldly instrument, the opera-glass.

Everybody has noticed that when objects are close to us they appear larger than when they are at a distance; it accordingly amounts to the same thing whether, in speaking of the power of telescopes, we say they magnify twice, four times, or a hundred times, or that they are brought within half, a quarter, or a hundredth of their distance. Thus there is a telescope at Lord Rosse's Observatory, at Parsonstown in Ireland, which is the finest yet constructed. Its highest magnifying power is 6,000, therefore every object we look at with it is brought within the 6,000th of its distance from us. Looking at the moon, for instance, we know that our satellite is distant some 240,000 miles from us; we have, therefore, only to divide that number by 6,000 to find that by means of this wonderful instrument the moon is brought within 40 miles of the earth. This statement, however, is not strictly true, for it supposes the whole of the apparatus used to be theoretically perfect.

Kepler, whose great name is now-a-days always associated with that of Galileo, but who during their lifetime was somewhat his rival, substituted for the single lens forming the eye-piece a combination consisting of two convex lenses, in order to obtain a larger field for observation than that given by the single bi-concave. This combination is commonly known as the astronomical eye-piece. It reverses the object looked at, but for astronomical purposes this defect is of no consequence.

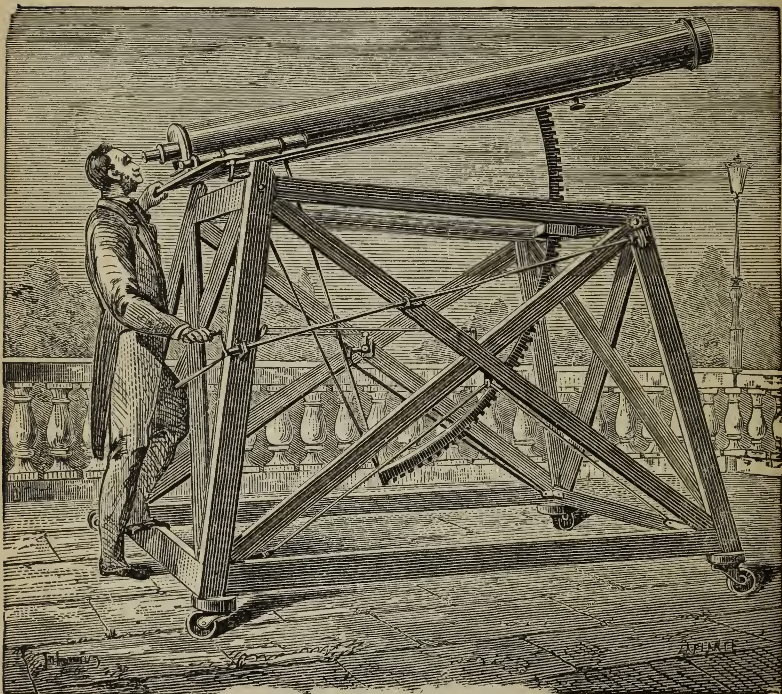

FIG. 42.—The Astronomical Telescope.

The instrument shown in the above figure represents an astronomical telescope reduced to its simplest form.

Fixed parallel to the axis of the larger telescope is the finder, a small telescope of low power and large field, used for finding celestial objects not easily visible to the naked eye. It is so arranged, that when the object is found and carried to its centre, it is also in the centre of the field of the larger instrument. The handle and the two toothed wheels serve to raise or lower the telescope, which is movable on the horizontal axis, which supports it in front, so that it may be directed to any part of the heavens the observer may desire.

The following figure shows the arrangement of the lenses, and the path of the rays through them, in telescopes of this form.

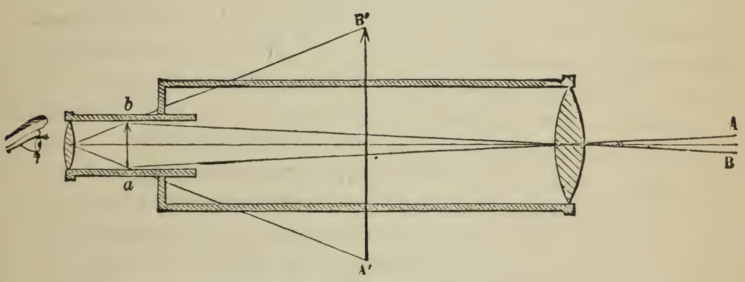


FIG. 43.—Section of an Astronomical Telescope.

The convex lens which serves as an object-glass, gives at *a b* a reversed image of the star A B. The small convex lens which acts the part of an eye-piece, enlarged this reversed image without changing its position, and causes it to be seen in the line A′ B′. This eye-piece is fixed at the extremity of a tube, which is smaller than that containing the object-glass, and slides easily backwards and forwards from the spot where the image *a b* is found. The latter is an indispensable condition, for it is rare to meet two persons whose eyes are of the same focus; besides, the image *a b* will fall at a different spot for objects at different distances: thus, if you are looking at the moon, and suddenly turn the instrument on to a distant nebula, you will find that the eye-piece requires adjusting. In showing ordinary observers an object in the telescope, it is well to insist on their moving the eye-piece backwards and forwards until distinct vision is obtained, for it often happens that people will say they see an object quite distinctly, when it is in reality misty, and will generally refuse to allow the focus to be altered. It is very singular how human vanity or complaisance will step in when some persons are looking through a telescope. They seem to think that there is some disgrace or rudeness involved in their not being able to see what their predecessors at the instrument have seen. Poor John Leech leaves us an amusing instance of this in a comic cut inserted in one of the early numbers of our old friend *Punch.* A gentleman is endeavouring to show a lady a distant steamboat through a telescope, but she has it accidentally pointed at two swans that are swimming on the margin of the lake below; consequently when he asks her if she sees the steamer, she replies that "she sees it most distinctly, and there are two of them," a pretty good proof that the instrument was not only pointed at the wrong object, but was out of focus as well.

In constructing a telescope similar to the one described above, the object-glass ought to be of considerable diameter and of long focus; the eye-piece, on the contrary, should be comparatively small and of short focus. A little consideration will show the reason of this. An object-glass of long focus will form a large image at the point *a b*, and the eye-piece of short focus will magnify this image more than another lens of less convexity. It is, however, on the size, length of focus, and perfection of workmanship of the objective that the excellence of the telescope depends; large object-glasses are consequently rare, and are only to be found in observatories of the first class. The object-glass of the large telescope at the Observatory at Paris is nearly fifteen inches in diameter, and the highest magnifying power capable of being employed with it is 3,000. The Observatory of Pulkowa, near St. Petersburg, possesses a similar instrument, and the Observatory at Chicago, United States, a still larger one, measuring between eighteen and nineteen inches in diameter. But the largest of all is an objective in the possession of Mr. Buckingham, an amateur astronomer, who has an observatory near London, which is twenty inches in diameter, and twenty-eight feet in focal length.

The eye-pieces of astronomical telescopes are of different powers, and are changed according to the class of object to be observed. Thus, in taking a general view of the moon, a low power would be used. If you wished to examine any particular mountain, you would raise the magnifying power by inserting a stronger eye-piece. The power used also depends on the state of the atmosphere. For instance, on warm evenings, when the air is charged with moisture, the tremulousness of the atmosphere is so great, that it is often only possible to use the very lowest power. By combining four convex lenses together, we obtain what is called a terrestrial or erecting eye-piece, which has the property of *re-reversing* the image formed by the objective. The eye-pieces of all telescopes for use on land or at sea are made on this principle. The same effect may be obtained, as we have already shown in fig. 41, by using a concave lens, but in this the field of view is much diminished.

Hitherto we have only spoken of refracting telescopes or those instruments provided with a convex object-glass, to collect and refract the rays of light given off by the object we are desirous of examining; but there is another and very important class of instruments, in which the object-glass is replaced by a reflecting mirror. The first reflecting telescope was invented by Dr. Gregory, an English philosopher, about 1650. It consisted of a brass tube, at the lower extremity of which was fixed a concave mirror made of metal, and provided with a hole in its centre for the insertion of the small tube containing the eye-glass. Towards the other end of the telescope was placed a second and smaller mirror, which reflected the image formed by the large mirror, through the eye-piece to the eye. The following figure will show the path of the rays in the Gregorian telescope.

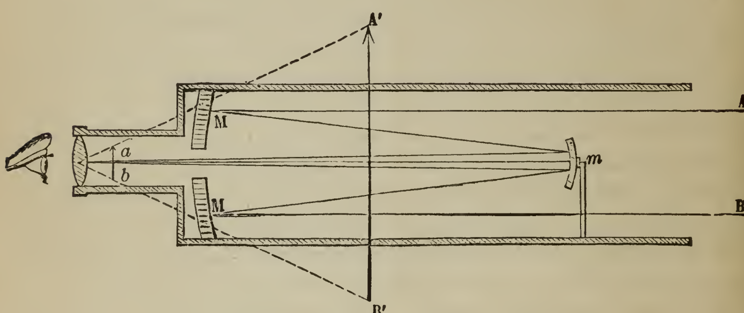


FIG. 44.—Section of the Gregorian Telescope.

The rays A B, proceeding from the object at which the instrument is pointed, are first reflected from the surface of the principal mirror M M on to the small mirror *m*, whence they proceed to form a magnified image at *a b*, which is then again enlarged by the eye-piece appearing to the eye as if placed at A′ B′. The focus in the Gregorian is altered, not by sliding the eye-piece backwards and forwards but by moving the mirror *m*, which is provided with a long screw, to which is attached a handle. At first sight a reflecting telescope has the appearance of a very stumpy-looking refracting instrument, but one instant's examination will show the observer that the usual object-glass is absent at the end of the tube. In fig. 45 we have a Gregorian telescope, mounted on a tripod stand.

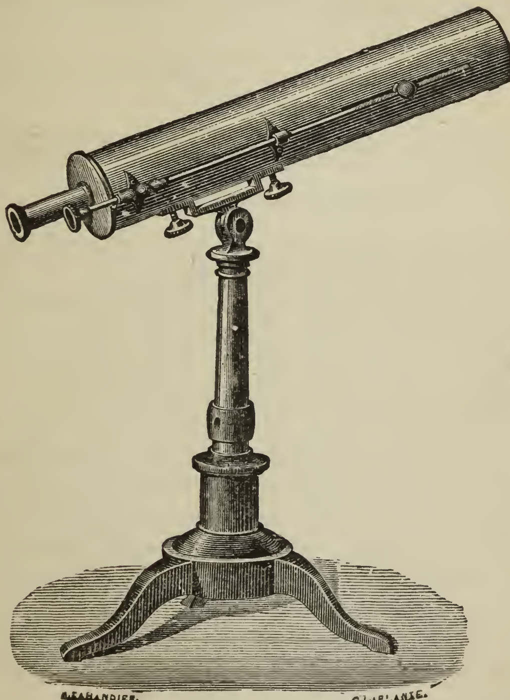

FIG. 45.—Gregorian Telescope.

Whilst experimenting on the Gregorian telescope, Newton made certain improvements in its construction, which we shall proceed to describe. A glance at fig.

46 will show that the path of the rays is much more simple than in the instrument we have just noticed.

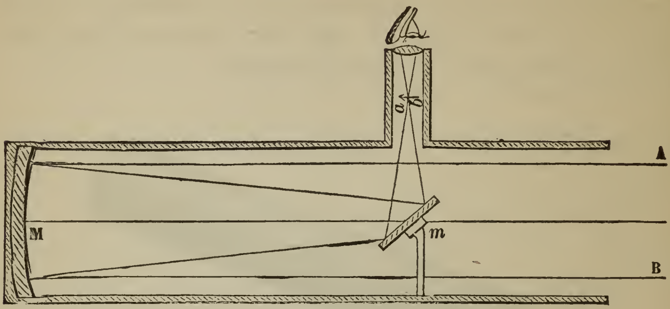


FIG. 46.—Section of a Newtonian Telescope

The rays of light A B are first reflected from the concave mirror M on to the surface of the small plane mirror *m*, which is placed at an angle of 45°, and reflects them as far as the point A′ B′, where they form the image to be magnified by the eye-glass. It is therefore at the *side* of the instrument, and not at the end, as hitherto, that the observer is placed, and at right angles to the path of the rays. Observers looking at an object through a Newtonian telescope for the first time are generally sufficiently astonished to find that there is really no difficulty after all in seeing round a corner. We shall presently return to the subject of Newtonian telescopes, which were abandoned by astronomers for many years, until they were brought into use again by M. Foucault, a distinguished French philosopher.

Towards the end of the last century Sir William Herschel invented and constructed the reflecting telescope which bears his name. His great object was to avoid the loss of light consequent on the double reflection which took place in all instruments constructed up to that time, and he succeeded at last in making a telescope in which the observer looked directly through the eye-piece at the image formed by the mirror, which was inclined in such a manner that the rays were reflected to the lower edge of the open end of the tube. In using this kind of telescope the observer is placed with his back to the object he wishes to examine, a position that is even more astonishing to those unaccustomed to the use of a Herschellian telescope than the one assumed when employing an instrument of the Newtonian construction. This position has the defect of causing a small portion of the rays proceeding from the object to be intercepted by the head of the observer, but the amount of light lost is so small in comparison to the size of the mirror that in practice it amounts to nothing.

The dimensions of the telescope constructed by Herschel were enormous for that day. It measured 40 feet long, and the mirror was 4 feet in diameter. It was supported by a complicated system of scaffolding, pulleys, and cords, and was capable of magnifying an object 6,000 times. It was by means of this splendid instrument that Sir William Herschel made those wonderful discoveries in astronomy which are inseparably associated with his name. With it he discovered the planet Uranus, many of the double stars, and a large number of nebulæ, which up to that time were unknown. His son, Sir John Herschel, inherits his father's talents as an astronomer, and has enriched science with numberless observations and discoveries of the greatest importance made with this fine instrument. Fig. 47 shows the construction of the Herschellian telescope, and the path of the rays may be easily followed by the student without any help from us.

The vulgar, ever prone to make mountains out of molehills, magnified the power of Sir William Herschel's telescope beyond all bounds. Stories were circulated about his having given a dinner in the interior of the tube to a select party of friends, but as the diameter of the telescope was only a little more than 4 feet, the entertainment, to say the least of it, would have proved

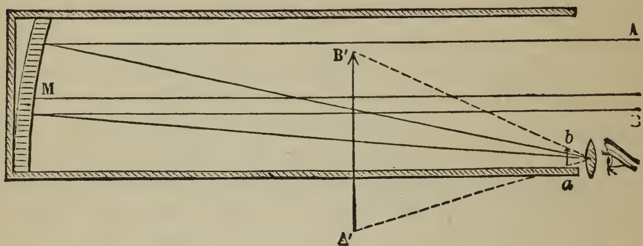


FIG. 47.---The Herschellian Telescope.

somewhat inconvenient to the guests. Another story, which was credited by great numbers of people, was that he had discovered inhabitants in the moon, but that he hesitated to make the matter public for fear he should be prosecuted for spreading atheistical notions. In fact, the tales told of Sir William Herschel's telescope were endless, and caused the astronomer great inconvenience by attracting crowds of idle people to the neighbourhood of Slough, where he vainly endeavoured to carry on his investigations in peace and quietness. It was in vain that these silly assertions were disproved again and again. Having once believed them, people were slow to reject them, and the story of the dinner was told over and over again for many years.

The instrument above described is one of those known as *front view telescopes*, on account of the image of the star being reflected from the surface of the mirror, which was placed obliquely at the bottom of the tube in front of the observer, who examined it by means of the eye-piece without any other reflection taking place, thereby effecting a saving of light, which fully compensated for any loss caused by the mirrior being placed askew. The concave mirror made by Herschel alone weighed a ton, to say nothing of the enormous tube and its fittings. Herschel had consequently to invent a special apparatus for holding and moving this gigantic instrument. The moving gear consisted of a mass of beams, pulleys and cords, reminding one more of the rigging of a ship than of a philosophical instrument. The apparatus for moving the telescope appeared so complicated to the casual observer, although in reality it was very simple, that it doubtless contributed in no small degree to the propagation of the fanciful stories we have already spoken of.

The performances of this splendid instrument hardly came up to the expectations of those who saw it in progress. Herschel, it is true, was enabled by its means to use a power of from 3 to 6,000, but he could only use these amplifications on a few objects—the planets, for instance, giving so little light under a high power as to become indistinct and misty. In 1802 Baron von Zach, in his *Monthly Astronomical Compendium*, went so far as to say that this colossal instrument was not of the slightest utility, that no discovery had ever been made with it, and that it ought to be considered merely as an optical curiosity. Subsequent events, however, proved very conclusively that Baron von Zach was utterly wrong in his statements and prophecies.

The telescope constructed by Herschel, although very wonderful for the day in which it was made, has long since been eclipsed by that belonging to Lord Rosse, and erected by his late father at Birr Castle, near Parsonstown in Ireland. It is superior to Herschel's instrument both in point of size, and workmanship. The late Lord Rosse, not fearing that his dignity would be compromised by such an act, went boldly to work, and learned to polish mirrors like an ordinary workman, the consequence of which was that he could bestow unusual pains upon the finishing of the speculum. His Lordship not only learnt the mere handicraft of speculum polishing, but went deeply into the engineering difficulties of the operation, and succeeded in inventing many improvements for diminishing labour and rendering the form of the surface more perfect. The specula ground and polished under Lord Rosse's method are almost entirely free from what is called spherical aberration,—that is to say, all rays proceeding from a single point of light, such as a star, are collected into a single point instead of being scattered in a round mass. This freedom from spherical aberration is of course necessary to produce perfectly distinct images. In his *Life of Newton* Sir David Brewster calls it one of the most marvellous combinations of art and science yet seen in the world.

The tube of Lord Rosse's instrument is 55 feet long, and weighs 6½ tons. In form it may be compared to the chimney of a steamboat of enormous size. At one end it terminates in a kind of square box, within which is contained the mirror, whose diameter is 6 feet, and which weighs nearly 4 tons. The weight of the whole apparatus is consequently nearly 10½ tons, or four times as much as Herschel's. It is erected on an oblong mass of masonry, 75 feet in length from north to south, between two solid walls nearly 50 feet high, which serve as supports for the mechanism intended to move this enormous tube in all directions. To the walls are also fixed movable staircases with platforms that can be brought up to the eye-piece with the greatest facility, no matter in what position the telescope may be placed. This noble instrument has penetrated space to a distance perfectly unattempted before its existence, and has resolved numerous nebulæ into masses of stars that until then were supposed to be mere clouds of luminous matter. The exact forms of other nebulæ have also been accurately determined by this telescope, which fully deserves the glowing eulogium passed upon it by the Duke of Argyle in his presidential address at the meeting of the British Association at Glasgow, in 1855. "This instrument," said his Grace, "in extending the range of astronomical science as it has done, has been the means of throwi g certain doubts upon the laws that govern the motions of the heavenly bodies, and render it possible that certain of the far-distant nebulæ are regulated in their movements by other laws than those to which the members of our own system are subjected."

The clearness with which this telescope exhibits every object within its range is so great that the most distant nebulæ are seen with as great distinctness as the nearest planet. On directing it towards the moon, which is only distant from us about 24[illegible],000 miles, the surface of our satellite may be explored with a facility almost as great as that with which we examine the details of a landscape with an ordinary telescope.

Maedler, a German astronomer, who has measured nearly every mountain and valley on the moon's surface with the greatest exactitude, stated some years before Lord Rosse's telescope was perfected that if a monument as large as one of the Pyramids existed on the surface of the moon it could have been readily distinguished by the instruments then in use. With Lord Rosse's telescope we can see the surface of our satellite so much enlarged that a space 220 feet square could be readily perceived by a good observer. This enormous eye, measuring 6 feet in diameter, would hardly show us a lunar elephant; but it is certain that if a troop of buffaloes, or animals analogous to them, crossed the field of vision, they would undoubtedly be perceptible.

Masses of troops marching backwards and forwards would also be plainly visible, and we may assert with something like absolute certainty that there are neither towns nor villages in the moon, nor any buildings as large as St. Paul's of London or the colossal railway stations of that metropolis.

This telescope, as we have said before, is the largest hitherto constructed, and cost its noble constructor more than 25,000*l*. It must also be recollected that it was not a mere scientific toy belonging to an amateur philosopher, but a real working instrument in the possession of a true man of science, who did work with it that will render his name famous while civilization lasts. The present Lord Rosse seems worthy in every way of his father's great name, and has already enriched astronomical science with numerous valuable observations.

We shall finish this chapter by a description of the Newtonian telescope constructed by M. Léon Foucault. The mirror, instead of being made of speculum metal, which is an alloy of tin and copper, is made of glass from the famous manufactory of St. Gobain. The first rough grinding having been finished, it passed into the workshops of M. Secrétan, the optician to the Paris Observatory, to receive its final polish and finishing touches from the hand of M. Foucault himself, the most careful optical tests being applied to it before the commencement of each operation.

The glass mirror having reached the degree of perfection desired, was then silvered on its concave surface by being plunged into a bath of nitrate of silver, dissolved in water, and mixed with certain proportions of gum galbanum, nitrate of ammonia, and oil of cloves. Half an hour in this bath was sufficient for the deposition of a film of silver of sufficient thickness to bear polishing. When finished, the mirror was found to reflect 92 per cent. of the light incident on its surface, the loss in the case of achromatic object-glasses and metal specula being 20 and 35 per cent. respectively.

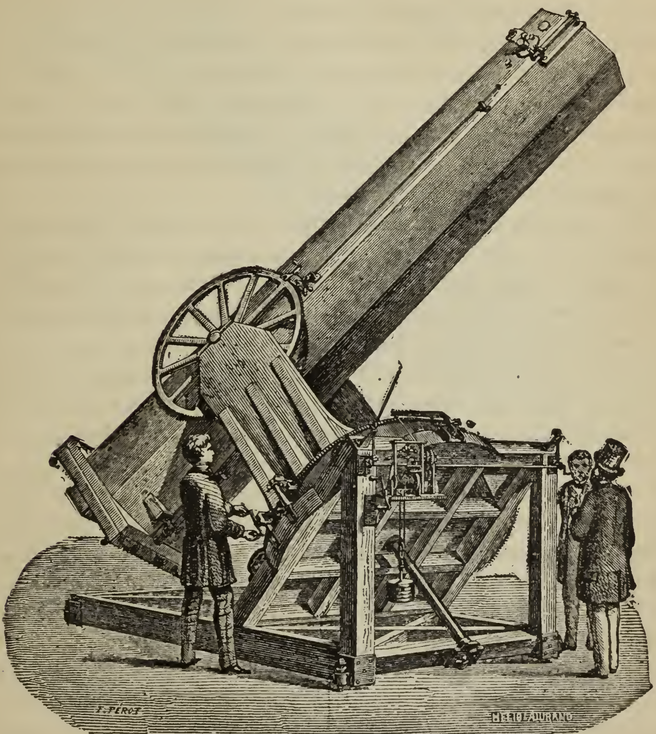

FIG. 48.—Foucault's Large Telescope.

The substitution of a parabolic glass mirror for the ordinary metal speculum offers the triple advantage of greater lightness, increased distinctness, and more brilliant images. Fig. 48 represents the large silvered glass telescope constructed under M. Foucault's direction for the observatory at Marseilles. It measures 32 inches in diameter, and has a focal length of a little more than 16 feet, and is put in motion by clockwork of a very perfect description, so that when once pointed at a star or planet it follows the object, which would otherwise disappear on account of the rotation of the earth. The path taken by the rays is precisely the same as in Newton's telescope, the eye-piece being placed at the side of the tube, which is provided with a movable platform and staircase for the observer.

The optician to whose talent in his art this fine instrument is due, has recently executed several small telescopes upon the same model, at such a price as to bring them within the reach of amateurs with slender purses. The principal part of these telescopes, one of which is represented in fig. 49, (see next page), is the mirror, which is about 4 inches in diameter, and 24 inches' focal length. The body, which is cylindrical, is made of brass, and revolves on two pivots placed horizontally at about one-third of its length from the bottom. The bearings on which the pivots move consist of two upright standards of metal, which are connected at the bottom, and revolve on a pin in the middle of the plate of the tripod stand. They are made of such a height that the lower portion of the instrument may pass between them, when it is necessary to observe objects in the zenith. By the turn of a screw the whole of the upper portion of the instrument may be dismounted and fixed on a lower standard, so that the observer may work sitting down if necessary. The body of the telescope is provided with a finder. One of the great advantages of this form of instrument is that it can be used for observations on the zenith without giving the observer those unpleasant cricks in the neck so inseparable from the use of ordinary telescopes in a nearly upright condition. The mirror will bear a power of 220 diameters,

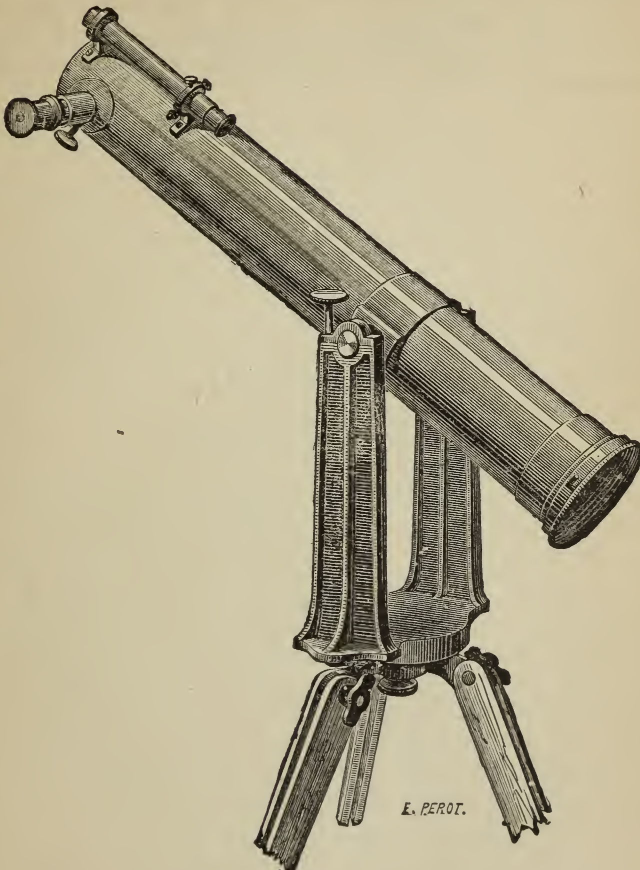


FIG. 49.—Foucault's Small Telescope.

and shows the mountains of the moon, the phases of Mercury and Venus, Saturn and his ring, Jupiter and his satellites, and a large number of double stars and nebulæ. It is provided with a set of eye-pieces, so that any power almost from 50 to 220 diameters may be used at will. The figure on the opposite page will give the amateur a good idea of the form and size of this instrument.

# PART III.

## NATURAL MAGIC.

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## CHAPTER I.

### THE MAGIC LANTERN.

The illusions of which we have spoken in the first part of this work depended principally on the nature of man's vision, who, we found, was the constant and heedless victim of his own powers of sight. We shall now examine a series of illusions that are still more extraordinary, but which have nothing to do with the deceptions practised on us by our visual organs. Instead of being deceived by ourselves, we shall find that we are led astray by others whose knowledge of the laws of optics is greater than our own, enabling them to construct instruments capable of amusing us or imposing on us, according to our ignorance of natural laws. Let us hope, however, that the science of optics has now become so familiar to most educated people, that no such thing as a real imposition can take place, although at the present day there are so many exhibitions of the marvellous that ordinary observers have the greatest difficulty in accounting for them. In former ages, when the knowledge of science was confined to a certain class, the commonest optical facts of the present day were taken advantage of to delude the ignorant. The deceptions practised by the ancient priests of Egypt, Greece, and Rome were undoubtedly many of them of this description. It is a well known fact that both plane and concave metallic mirrors were used by the ancients, and a passage in Pliny gives an account of certain glass mirrors that were made at Sidon. Aulus Gellius, quoting Varro, speaks of the reflecting properties of hollow mirrors, and we shall see, as we go on, what a number of illusions may be practised by means of a series of plane mirrors arranged in a particular way. But we will first devote a short time to the curious historical facts connected with the principle of the magic lantern which took place long before the modern invention of this instrument by Father Kircher.

Brewster says, when treating of this subject, that there can be little doubt that the concave mirror was the principal instrument used in connexion with the pretended apparitions of the gods and goddesses in the ancient temples. In the meagre history of these apparitions that has come down to us, we can easily perceive the traces of an optical illusion. In the ancient temple of Hercules at Tyre, there existed a certain seat made of consecrated stone, out of which the gods rose, apparently at the will of the priests. Æsculapius appeared frequently to his worshippers in his temple in Tarsus, and the temple of Eugenium was famous for the number of gods and goddesses which were constantly visiting its sacred precincts. Iamblicus tells us that the priests showed the gods to the people in the midst of smoke; and when the great magician Marinus terrified his auditory by suddenly showing them the statue of Hercules in the midst of a cloud of incense, it was undoubtedly a woman who performed the part, dressed up in man's robes for the occasion.

The character of these spectacles in the ancient temples is admirably described by Damasius, and there is no difficulty in seeing that optical illusions were the means employed to delude the audience. He describes the apparition on the wall of a large spot of white, which at first appeared at a distance, but gradually came nearer and nearer until at last it assumed the form of a divine or supernatural being, of severe yet mild aspect and of great personal beauty. This being the Alexandrians immediately honoured as Osiris or Adonis.

Amongst more modern examples of this illusion may be mentioned that of the Emperor Basil of Macedonia. Inconsolable at the loss of his son, this potentate had recourse to the prayers of the Pontiff Theodore Lantabaren, who was celebrated for his power of working miracles. The conjurer showed the Emperor the image of his dead son magnificently attired and mounted on a splendid war-horse. The young man dismounted, and, going up to his father, threw himself into his arms and disappeared. Salvertius, in speaking of this story, observes judiciously, that the deception could only take place through the agency of some person who closely resembled the Emperor's son, and that the trick would have been easily discovered when the person embraced the Emperor. A better explanation of the affair is, however, afforded by supposing that the Emperor saw an aërial image of a person resembling his son, and that when he rushed forward to embrace him it disappeared.

The accounts of the operations of the ancient magicians are too meagre to give us any idea of the splendour of some of these ancient ceremonies. A system of deception such as this, employed as a means of government, must have brought into requisition not only the talents of all the learned men of the day, but a crowd of accessories calculated to astonish and confound the judgment, fascinate the senses, and facilitate imposture.

An account of an instance of modern necromancy has been left us by Benvenuto Cellini, who played a prominent part in a case of this sort.

He accidentally made the acquaintance of a Sicilian priest, a man of great genius and acquirements, and well versed in Greek and Latin classical lore. One day the conversation turned on necromancy, and the great goldsmith told him that he had the greatest desire to know something about this wonderful art, and that he had felt all his life a great curiosity to penetrate its mysteries.

The priest replied, that a man ought to have a very resolute and fearless character to study this art; but Benvenuto answered he had both resolution and courage. The priest went on to say, that if he had the heart to try, he would be the means of obtaining the fulfilment of his wishes. They consequently agreed upon a plan of necromantic study. One evening, Benvenuto invited one of his companions, Vincenzio Romoli, to take part in some experiments that were to be made amongst the ruins of the Coliseum. They there met the Sicilian priest, who after the manner of the ancients began to describe a number of circles in the air in the most imposing manner. He had brought with him various gums and perfumes, and had made a fire, into which his assistant necromancer was to throw them at the proper time. He commenced his conjurations, the ceremony continuing about an hour, when there appeared legions of demons, in such numbers that the whole of the ruins seemed filled with them. Benvenuto was nearly fainting with the perfumes, when the priest roused him by telling him to ask for something. He replied, that he wished to be transported to the side of his Sicilian mistress; but the demons were evidently unpropitious, for nothing came of it. His instructor, however, told him that they must repeat their experiments a second time, and that Benvenuto must bring with him a child that had never committed sin. The next time Benvenuto took with him a boy of twelve years old whom he had in his service, and his friends Romoli and Guddi. When they arrived at the place of meeting, they found the priest had made the same preparations as before. This time, however, he used more powerful conjurations, calling on a number of demons by their names, in Hebrew, Greek, and Latin; so that the ruin was filled with a still greater mass of them than on the other occasion. The fire and perfumes were put under the charge of Guddi and Romoli, and he gave Benvenuto a magic picture to hold in a certain direction, the boy being placed underneath it. The priest told him again to wish to be in the company of his lady love, but on his expressing the wish, the magician told him that the demons still refused to do his bidding in this way, but that he should visit her once more in a month's time. The poor boy underneath the magic picture was seized with a terrible fright, and exclaimed, that he saw millions of ferocious spirits and four giants, all endeavouring to break through the magic circle the priest had formed. All there were evidently in a most abject state of terror, and remained in the place until the church bells began to ring for morning prayers, when they returned home, the boy declaring that two of the demons preceded them, dancing and gambolling before them, and sometimes running along the housetops.

The priest then advised him to try another spiritual *séance*, and endeavour to induce the demons to point out sundry pots of buried gold, so that they all might become rich, but it does not appear that the priest's advice was followed.

It is impossible to read the foregoing description of what happened, without being convinced that the whole affair was an optical illusion, and not the mere result of the imagination of those who took part in it. The smoke was evidently caused in order to afford a field for the exhibition of painted images reflected by concave mirrors, and the circle was formed in order that those within it might be within range of the images formed on the smoke. The mirrors reflecting the images of the demons had undoubtedly already been arranged so that they would fall just above the fire, and become visible when the gums began to burn with a smoky flame. The perfumes were simply to help to stupify the spectators, and aid in working on their imaginations for those occurrences which were beyond the reach of optics, for the poor unfortunate boy saw things that his companions did not, even to a couple of demons dancing through the streets in broad daylight. In fact, it is somewhat difficult to draw the line between reality and imagination in this case. No doubt the story is considerably exaggerated by Cellini, who was a fervid Italian, and prone to believe in wonders, as is instanced by his wish to study the black art. The priest, too, whom he describes as a man of genius, no doubt had a great influence over the famous artist, and made him see a great deal more than was really there.

The introduction of the magic lantern provided the magicians of the seventeenth century with a very powerful instrument with which to continue their deceptions. The use of the concave mirror, which does not appear to have had any accessories worth speaking of, required a separate apartment, or at least a hiding-place of some sort that was difficult to discover under ordinary circumstances; but the magic lantern, inclosing as it did the lamp, the optical apparatus, and the figures in a comparatively small space, was particularly appropriate to the wants of the Homes and Davenports of the day, who until then had never possessed anything so convenient and portable.

The magic lantern shown in figures 50 and 51 consists of a dark box, containing a lamp and a concave metallic mirror, constructed in such a way that the

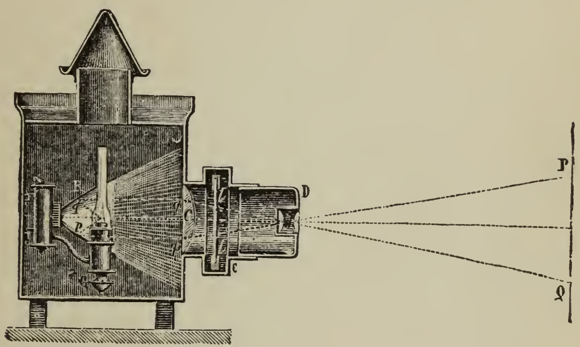



FIG. 50.—Section of the Magic Lantern.

whole of the rays proceeding from the lamp are reflected through the aperture holding the optical portion of the apparatus. In front of the box is fixed a double tube C D, one-half of which (D) slides in the other. A large plano-convex lens *c* is fixed at the inner extremity of the double tube, and a small one at its outer end. To the fixed tube C E is attached a groove *b b*, which serves to hold the painted glass. These glasses, or slides as they are generally called, are painted with strong transparent colours.

The direct light of the lamp G, as well as that reflected by the mirror and passing through the lens *c*, is so concentrated as to project a brilliant beam of light through the painted slide, which being in the conjugate focus of the large plano-convex lens *d*, the pictures on the glass are refracted in a magnified form on the white cloth P Q.

The magic lantern, therefore, consists of a box to hold the lamp, a concave mirror, and a convex lens to concentrate the light on the slide, and a second convex lens to throw the image on the screen.

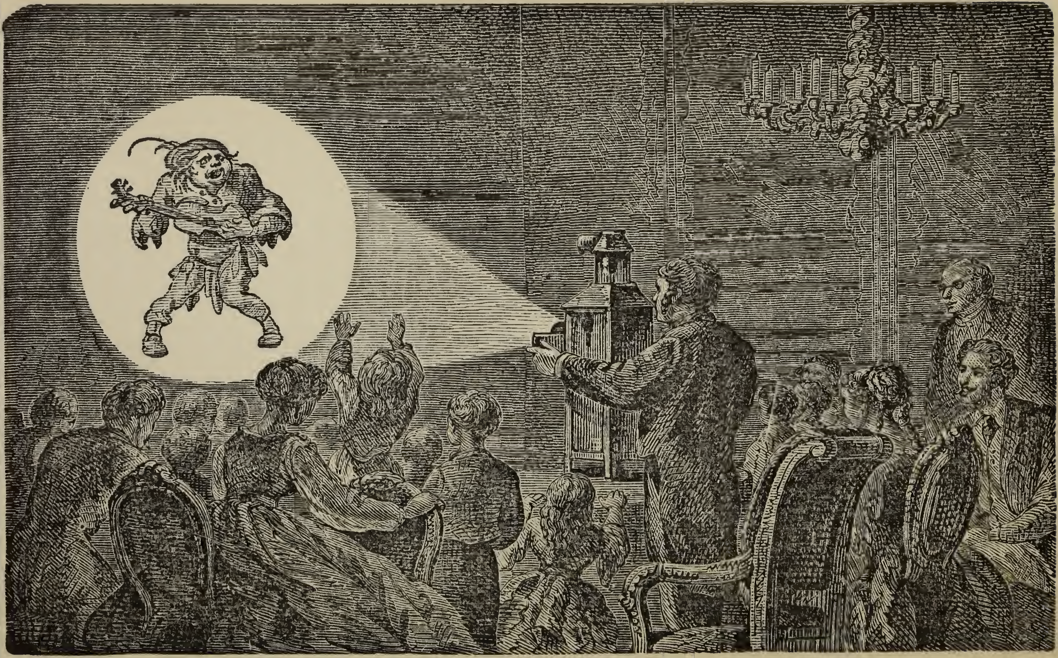


FIG. 51.—Magic Lantern.

## CHAPTER II.

### THE PHANTASMAGORIA.

The phantasmagoria may be described as a perfected magic lantern, and bears the same relation to its prototype that a shilling telescope bought in the Lowther Arcade does to one of Dollond's or Ross's field glasses. The position of the spectators, too, is different, being on the other side of the scene which receives the magnified pictures, already described when speaking of the magic lantern.

The phantasmagoria lantern is generally mounted on a stand provided with castors so that it may be moved about at will. It consists of a box as represented in fig. 52, inclosing a lamp with a metallic reflector, the bundle of rays being sent through the centre of the tube containing the slide and lenses, as before described. The chimney serves to carry off the products of combustion generated by the lamp. In fig. 53 we have shown the interior of the tube containing the lenses. Between this tube and the body of the lantern there is a space within which slide the glasses whereon are painted the figures and landscapes that are to be thrown on the white screen. The luminous rays given off by the reflector in the interior of the lantern pass through a plano-convex lens placed with the flat side outwards. In front comes the double convex lens, or object-glass, which can be moved backwards and forwards by means of a rack and pinion. There is also a movable diaphragm, which is worked with a couple of cords, by pulling which the aperture is made larger or smaller at will. By moving the lantern backwards and forwards, working

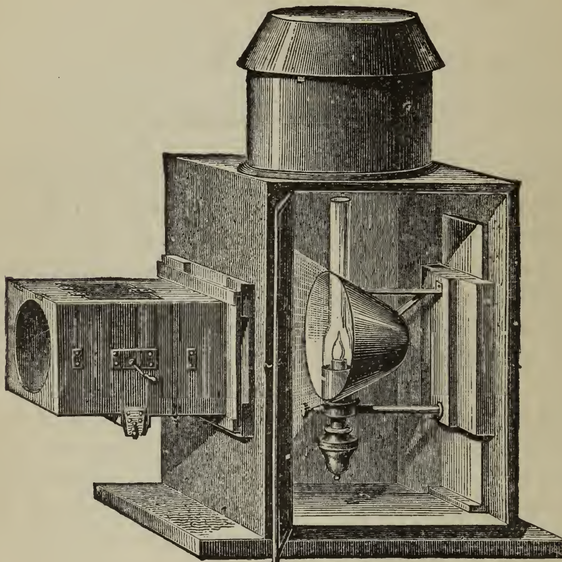


FIG. 52.—The Phantasmagoria.

the rack and pinion and the diaphragm at the same time, the view seen by the spectator seems to advance and recede. The pictures are painted on glass with transparent colours, the glasses being generally about five inches in diameter. To render the illusion perfect it is necessary that the spectator should be placed in a partially dark room, being separated from the operator by the screen already mentioned. Everything being ready, the spectators having but little notion of the distance of the screen, a very small picture is shown to them first, the illumination being reduced to a minimum by pulling the cords which act on the diaphragm. The little picture first seen by them will appear to be situated at an enormous distance; but as the lantern is brought almost imperceptibly nearer to the screen, the image appears to advance towards them in a very sur-

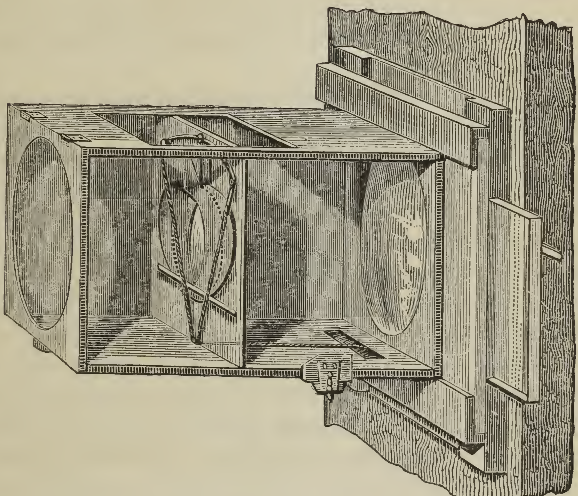


FIG. 53.—The Fantascope.

prising manner, at last appearing almost as if it were going to fall upon the spectators.

Robertson, an English optician who was settled in Paris some fifty years since, was one of the first to exhibit the phantasmagoria with success. In order to obtain the best results he used a room some sixty or eighty feet long, and twenty-four wide, which he hung entirely with black. Of this a strip twenty-five feet long was cut off and devoted to the manipulation of the phantasmagoria. This portion of the apartment was separated from the spectators by a white calico screen, tightly strained from side to side, and at first concealed from view by a black curtain. The calico screen, which was about twenty feet square, was well soaked in a mixture of starch and fine gum arabic, in order to render it semi-transparent. The floor was raised about four or five feet at one end in order that the whole of the spectators might have a free and uninterrupted view of what was going on.

It is undoubtedly to Robertson that we owe most of the improvements in the phantasmagoria. The success of his performances in Paris during the first Revolution has never been equalled by any similar exhibition. The enthusiasm excited amongst the Parisian public at the time surpassed that awakened even by Cagliostro and Mesmer. The spirit which guided Robertson in exhibiting these wonders was totally opposed to that which animated the two charlatans just mentioned. Robertson, unlike them, sought to spread the notion that there was nothing occult or supernatural in the marvels he exhibited, but that they resulted simply from the application of a few simple laws of optics. We shall presently give an account of one these famous *séances*, which were powerful enough to distract the attention of the people of that day from the stormy events that were going on around them; but we will first allow our author to tell the story of his experiments in optics in his own words.

"From my very earliest infancy," he says in his Memoirs, "my lively and passionate imagination caused me to be dominated over by the marvellous in a very powerful manner. Anything that seemed to go beyond nature in any way, excited in me an ardour which then appeared to me capable of overcoming all obstacles in order to realize the effects I had conceived. Father Kircher, it was said, believed that the magic lantern was the invention of the Evil One. All the worse for Father Kircher, who was gifted with a great intellect, and many persons were tempted to say that he might possibly have some cause for believing in the diabolical origin of a simple optical instrument. But as the writer who has thus reproached Father Kircher with too much credulity has not cited those passages of the work in which this statement may be found, I did not think seriously of the matter. Who has not in his younger days believed in witches, hobgoblins, and compacts with the devil? I know I did, and worse; for I imagined and fully believed that an innocent old woman who was a neighbour of ours, really had dealings with Lucifer, as every one asserted. I even went so far as to envy her the power of conferring with the Evil One, and once shut myself up in my room with an unhappy live cock, whose head I cut off in the most barbarous manner, having heard that that was the most approved manner of summoning into one's presence the great head of all the demons. I waited for him several hours, calling on him to appear, threatening to deny his existence for the future if he did not appear, but all to no purpose. The books on magic and the black art that I had read had completely turned my head. I believed everything that was in them, and I desired ardently to perform the wonders they described, even with the aid of the devil. The *Magia Naturalis* of Porta, and the *Recreations* of Midorge, which treated simply of natural phenomena, had no effect upon me, but I was at last obliged to fall back on the principles involved in them, in order to create the diabolical appearances I had sought after in what I considered a truly supernatural manner, until at last my dwelling became a true Pandemonium.

"It is only our grandmothers, it has been said for a long time, who believe in magic, witches, and supernatural appearances; but the statement is hardly true, seeing how easily the country people fall a prey to the first cheat who chooses to invest himself with supernatural powers. We have sufficiently ridiculed the superstitions of the ancients, and numberless instances may be adduced which are a shame to their intelligence, and which gives, so to speak, a denial to the stories we have heard of their high state of civilization. But I believe, if we were to make a collection of all the stories of ghosts, of mysterious appearances, of communications between the living and the departed, of the discoveries of hidden treasures, &c., &c., which have taken place even since the Revolution, before whose power so many dark things have been brought to light, the collection would hardly be less bulky than that of the ancient superstitions now happily passed away."

Robertson then goes on to take great credit to himself for showing the world that all the superstitions concerning ghosts, spectral appearances, and other illusions of a similar nature, were to be easily accomplished by simply studying natural laws. He appears first to have begun his optical experiments with the solar microscope, and we hear of his landlord taking an action against him to recover damages for having pierced the doors of his rooms with innumerable holes. He studied the subject both theoretically and practically for many years, in company with his friend Villette, and at last announced a public *séance* at the Pavillon de l'Echiquier at Paris. A multitude of advertisements and prospectuses, written in the high-flown style of the time, were issued, and distributed throughout the city. The newspapers of the day are full of accounts of the extraordinary impression made on the minds of the Parisians by Robertson's wonderful exhibition. The old-fashioned word magic lantern was quite abandoned, and the new and high sounding Greek appellation, "phantasmagoria," was heard issuing from every one's mouth. There is an amusing account given of Robertson's exhibition in one of the contemporary journals, written by Poultier, one of the representatives of the people. He says: "A decemvir of the republic has said that the dead return no more, but go to Robertson's exhibition and you will soon be convinced of the contrary, for you will see the dead returning to life in crowds. Robertson calls forth phantoms, and commands legions of spectres. In a well-lighted apartment in the Pavillon de l'Echiquier I found myself seated a few evenings since, with some sixty or seventy people. At seven o'clock a pale thin man entered the room where we were sitting, and having extinguished the candles he said: 'Citizens and gentlemen, I am not one of those adventurers and impudent swindlers who promise more than they can perform. I have assured the public in the *Journal de Paris* that I can bring the dead to life, and I shall do so. Those of the company who desire to see the apparitions of those who were dear to them, but who have passed away from this life by sickness or otherwise, have only to speak, and I shall obey their commands.' There was a moment's silence, and a haggard looking man, with dishevelled hair and sorrowful eyes, rose in the midst of the assemblage and exclaimed, 'As I have been unable in an official journal to re-establish the worship of Marat, I should at least be glad to see his shadow.' Robertson immediately threw upon a brasier containing lighted coals, two glasses of blood, a bottle of vitriol, a few drops of aquafortis, and two numbers of the *Journal des Hommes Libres*, and there instantly appeared in the midst of the smoke caused by the burning of these substances, a hideous livid phantom armed with a dagger and wearing a red cap of liberty. The man at whose wish the phantom had been evoked seemed to recognise Marat, and rushed forward to embrace the vision, but the ghost made a frightful grimace and disappeared. A young man next asked to see the phantom of a young lady whom he had tenderly loved, and whose portrait he showed to the worker of all these marvels. Robertson threw on the brasier a few sparrow's feathers, a grain or two of phosphorus, and a dozen butterflies. A beautiful woman, with her bosom uncovered and her hair floating about her, soon appeared, and smiled on the young man with the most tender regard and sorrow. A grave-looking individual sitting close by me suddenly exclaimed 'Heavens! it's my wife come to life again,' and he rushed from the room, apparently fearing that what he saw was not a phantom.

A Swiss asked to see the shade of William Tell. The phantom of the great archer was evoked with apparently as much ease as the others. Delille, who was present, called for Virgil, whose Georgics he had lately translated. The poet appeared, having in his hand a laurel crown, which he held out to his French commentator. Many other equally extraordinary apparitions were shown at the will of various individuals in the audience, and towards the end of the evening Robertson showed his judgment, and under very difficult circumstances. A royalist who was present asked for the phantom of Louis XVI., the appearance of which would no doubt have raised a tumult amongst so many red-hot Republicans, had not Robertson replied that before the 18th Fructidor, the day on which the French republic declared that royalty was abolished for ever, he had had a receipt for bringing dead kings to life again, but that same day he lost it, and feared that he should never recover it again. The answer was said to have been whispered to Robertson by his friend Ponthieu, who saw the difficulty he was in. It was supposed that the demand was prompted by an agent of the police, who for some cause had a spite against Robertson. In any case the affair made such a noise that the next day the exhibition was prohibited by those in authority, and seals were placed upon the optician's boxes and papers. The exhibition was, however, afterwards allowed to be continued, and was so successful that it had to be transferred to the old Capuchin convent near the Place Vendôme.

The whole of Paris rang with eulogiums upon Robertson's wonderful exhibition at the Capuchin Convent. He had purposely chosen the abandoned chapel, which was in the middle of a vast cloister crowded with tombs and funereal tablets. It was approached by a series of dark passages, decorated with weird and mysterious paintings, and the very door was covered with hieroglyphics. The chapel itself was hung with black, and was feebly illuminated by a single sepulchral lamp. The whole assembly involuntarily remained grave and silent, and it was only when the first preparations for the exhibition were made, that the audience broke into a low murmur. Robertson commenced with an address on sorcery, magicians, witches, ghosts, and phantoms, and, having worked the spectators up to the proper pitch, he suddenly extinguished the single antique lamp already mentioned, plunging the assembly into perfect darkness. Then there arose a storm of rain, wind, thunder, and lightning. The bells tolled lugubriously as if summoning the dead from their tombs beneath the feet of those present; the wind whistled mournfully, the rain fell in torrents, the thunder rolled, and the lightnings flashed. But suddenly above all this confusion were heard the sweet notes of a harmonium, and in the far-off distance the sky was seen clearing gradually. A luminous point then made its appearance in the midst of the clouds, which gradually became the figure of a man, increasing in size every instant, until it seemed to be about to precipitate itself on to the spectators. A man in the front row was so frightened, that he uttered a scream of terror, when the phantom instantly disappeared. A series of spectres then issued suddenly from a cave. The shades of great men crowded together round a boat floating on a black and sluggish river, which the spectators had no difficulty in identifying as the Styx. The shadows gradually disappeared in the distance, getting smaller and smaller until they became invisible.

Robertson was extremely careful in all his entertainments to flatter the popular ideas of the day. For instance, one of his most famous exhibitions consisted in a picture of a tomb, in the middle of which Robespierre issued. The figure, as usual, walked towards the spectators; but when apparently within a few yards of them, it was struck down by lightning. Voltaire, Lavoisier, Rousseau, and other popular favourites then appeared on the scene, and disappeared again in the usual manner. Robertson generally ended his entertainment with an address something like the following:—

"We have now seen together the wonderful mysteries of the phantasmagoria. I have unveiled to you the secrets of the priests of Memphis. I have shown you every mystery of optical science; you have witnessed scenes that in the ages of credulity would have been considered supernatural. You have, perhaps, many of you, laughed at what I have shown you, and the gentler portion of my audience have possibly been terrified at many of my phantoms; but I can assure you, whoever you may be, powerful or weak, strong or feeble, believers or atheists, that there is but one truly terrible spectacle—the fate which is reserved for us all;" and at that instant a grisly skeleton was seen standing in the middle of the hall (fig. 54).

Even in those unbelieving days, when scepticism of

Fig. 54.—Phantasmagoria (Robertson).

every sort was riding rough-shod over the French people, Robertson had the greatest difficulty in disclaiming all approach to the possession of supernatural powers. Day after day he received applications from all quarters to reveal the secrets of the past, present, and future, to describe events that were passing in other countries; and it frequently happened, that after his entertainments, he would be asked by several members of his auditory to assist them in recovering property that had been lost or stolen from them. In the latter kind of cases he generally used to adopt the excellent plan of sending his would-be clients to the nearest police-office.

# CHAPTER III.

## OTHER OPTICAL ILLUSIONS.

By varying the disposition of mirrors, prisms, lenses, and light, an infinite number of the most surprising effects may be shown, with a comparatively small amount of trouble and expense. We shall, therefore, devote this chapter to the explanation of a large number of allusions, which have been devised by Robertson and other adepts in the art of honest deception.

One of Robertson's most famous delusions was the "Dance of Demons," an effect he discovered quite accidentally. One evening, while experimenting with the phantasmagoria, he suddenly found himself in the dark, when two persons, each bearing a light, crossed the room on the other side of the screen. A little window which happened to be between the lights and the screen, immediately threw its double image on the cloth, and the method of multiplying shadows was discovered.

The figures used in this experiment are cut out of fine cardboard, and may be made a foot high or thereabouts. They are placed on a second screen in front of the principal one, and by multiplying the lights, as shown in fig. 55, you may have as many shadows as you please. The effect is much heightened if the figures are cut out so as to show as lights when thrown on the screen. A little ingenuity shown in the arrangement of the distance and movements of the lights, will produce an


FIG. 55.—Wizard Dance.

endless amount of amusing effects. Thus, a small image of the principal figure may be produced by carrying the second light to a great distance, and the lesser figure may be easily made to jump over the former, by moving the candle in a semicircle over the light that is stationary. It is only necessary to recollect that whatever movements are made by the lights, the shadows of the figures follow their example. With a little ingenuity the heads and limbs of the figures may be made moveable; and if one assistant attends entirely to the working of the figures, and the rest to the lights, an infinite number of changes may be carried out. If mounted in a frame, they may be made to throw somersaults, fall down, or jump up in the air at will.

A knowledge of optics will often serve to explain with great ease the tricks played by conjurers and impostors on princes and other great people, for their own vile ends. It is well known that Nostradamus, on being consulted by Marie de Médicis on the future destiny of France, was shown by him in a mirror events that left no doubt on her mind that she would one day share the throne of the Bourbons. These illusions were possibly effected in the following manner, and may be readily understood by reference to fig. 56.

The throne in the first chamber is reflected in a mirror concealed in the canopy overshadowing a second mirror, placed carelessly on a table in the room in which the Princess and astrologer are standing. The arrangement of the mirrors is such that, on looking into the smaller glass, the Princess sees all that is going on in the adjoining chamber. The very fact of her consulting Nostradamus on her future fate, shows that under certain circumstances, at least, this clever woman was as silly as a child. It is not, therefore, to be supposed that she would notice that the mirror she was looking into was inclined at such an angle that it could not reflect her beautiful face. Nothing could be more natural, either, than that this magic looking-glass should be placed on a daïs, and shaded by a canopy. Nostradamus, who was a shrewd man, could no doubt pretty well see the course that events would take, and must consequently have felt quite safe in showing the Princess the throne of France occupied by Henry of Navarre. This was not the first time that the rulers of the earth were duped by so-called magicians, who possessed the knowledge that the angle of reflection was always equal to the angle of refraction.

We may also mention, while speaking on this subject, the adventure of the Emperor Alexander of Russia, *à propos* of a singular optical experiment at which he was present, which had for its end the changing of a man into a wild animal, or *vice versâ*. Certain cynics will possibly say that this is by no means difficult, and that it is an event that happens every day; but the clever trick at which Alexander was so astonished was not moral but purely physical. After having gained much money and fame in France, Robertson directed his steps towards Hamburg, where the Emperor was at that time stopping. He performed before the Czar an experiment that puzzled his Majesty beyond endurance. He showed him a man upon whose shoulders he saw successively the head of a calf, a lion, a tiger, a bear, and a whole menagerie of other animals. At last, the Czar could stand it no longer, and he suddenly rose, put his shoulder against the partition, and brought the whole to the ground with a loud crash, just at the moment that the confederate was assuming the form of a goat. If our readers would like to join the Czar in his discovery of the manner in which the trick was performed, they can easily do so.

The room in which this trick is to be performed should have a smaller one adjoining it, about eight feet square.

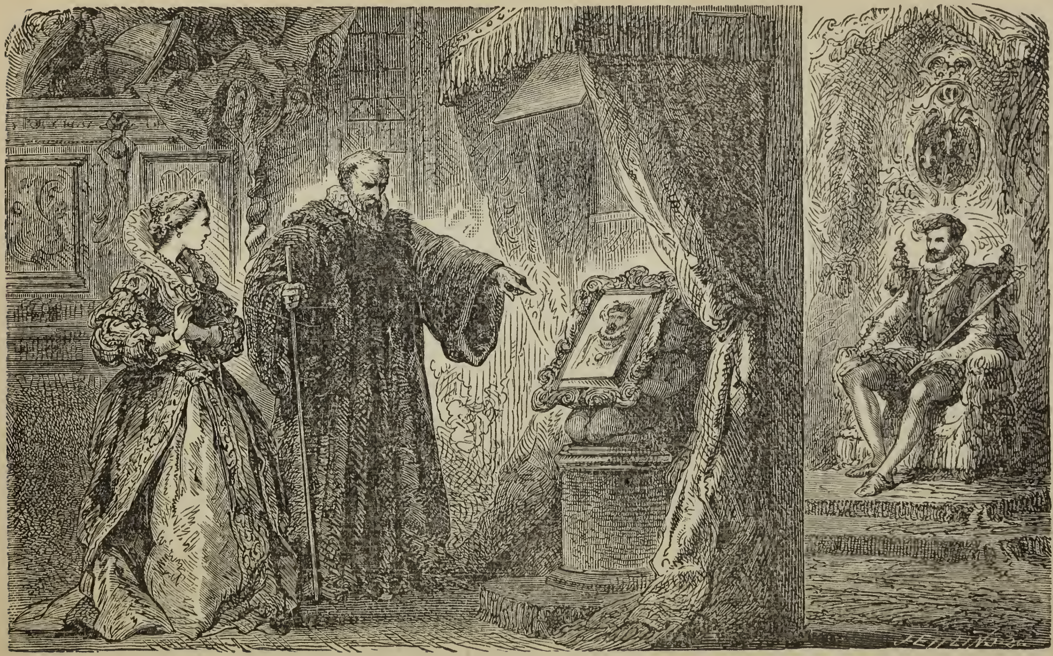


FIG. 56.—Nostradamus and Marie de Médicis.

The magician in the first place shows the small apartment to the spectator, who perceives that it contains nothing but an empty chair placed against the wall. The partition between the two rooms is provided with a small hole, covered with glass, exactly opposite the chair, and at about the ordinary height of the eyes. On the inner side there are two grooves, in which slide a block of wood containing a prism, as shown in fig. 57,

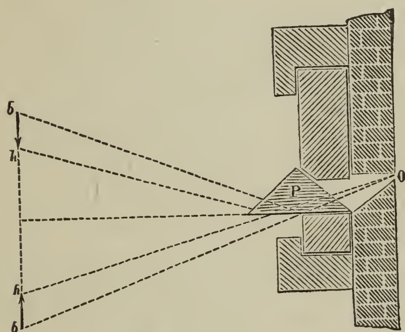



FIG. 57.—The Arrangement of the Reversing Prism.

which may be quickly and easily replaced by a piece of plane glass. On looking through this opening, the spectator sees a man sitting in a chair, but suddenly, without any apparent cause, the man changes into a goat, a sheep or some other animal. The sudden replacing of the prism, which takes place without the spectator perceiving it, causes him to see, not the floor with the man and chair upon it, but the ceiling, which is carpeted exactly in the same way, and is provided with a precisely similar chair, upon which is placed a goat or any other animal.

While looking at the goat, the plane glass is substituted for the prism, and the man reappears; another movement of the prism, and he changes into a sheep, a figure of a sheep having in the meantime replaced that of the goat. Of course it is necessary not merely to have the walls, floors, and chairs precisely alike, but they must each occupy the same relation to each other. If it is desirable only to change the head, it is simply necessary to have a lay figure with a moveable head, dressed precisely in the same manner as the living operator, in the upper portion of the chamber. At the end, by the substitution of the empty chair, the individual may be made to disappear entirely.

There may often be seen in the streets of London, a man showing a wonderful instrument, consisting of a telescope cut in two, the two portions being separated from each other by an interval of three or four inches. On looking through the instrument, the spectator of course sees the object at which it is pointed; but what is his astonishment to find, that when the showman places a brick between the two halves of the instrument he sees just as well as before. The showman generally informs him that the instrument in question has such powerful lenses, that it will not only see through a brick, but even through a policeman's head if it happened to be in the way; and the spectator, having paid his penny, goes away perfectly mystified, until, like the young lady who believed that all machinery was worked "by a screw, somehow," he comforts himself with the idea that the trick is performed "by a mirror, somehow." The following figure will, however, soon clear up the mystery.

Let F M, L G be an ordinary telescope tube, to be separated in the middle by an interval large enough to insert a brick, the hand, or some other opaque object. The whole is fixed on a stand, consisting of a square tube with a couple of elbows to it. Between G and L a mirror (A) is placed diagonally, which receives the

FIG. 58.—The Goat Trick.

image of the objects to be looked at. This mirror sends the image downwards to another placed diagonally at C, a third being placed at D, and a fourth at B. The

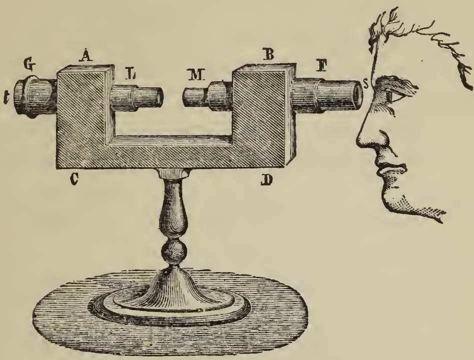



Fig. 59.—How to see through a Brick.

horizontal ray, meeting the mirror at A, is consequently bent downwards to C, then travels horizontally to D, when it is reflected upwards to B, in which it is seen by the eye. Of course a simple tube without any lenses at all would serve the same purpose, but the fact of its being a telescope serves to distract the attention of the too curious observer.

Another illusion of the same kind is often practised at fancy fairs and bazaars, when a spectator looking into what he supposes to be an ordinary looking-glass, sees his companions instead of himself. The way in which this is effected is very simple. A looking-glass is placed diagonally across a square box, the apertures in the sides being so arranged that the spectator does not perceive that he is looking into a glass that is placed at an angle. Of course the exhibitor endeavours to show the illusion to two persons at once; and if they are strangers to each other, and of the opposite sex, a great deal of fun is made out of the trick. A showman at Greenwich made an immense harvest by showing two such mirrors, one to all the young girls who wished to see their future husbands, and the other to all the young men who wished to see their future wives. Of course he had a tolerably good-looking male and female confederate to help him. With a couple of mirrors placed back to back in a square case, with an opening on each side, the illusion is still more perfect, as on looking through any of the holes the box seems to be quite empty.

The "Speaking Head" trick is performed on this principle. When the curtain is drawn up, the audience perceive an apparently living head placed on a small three-legged table, the curtain at the back of the stage being quite visible through the legs. By and by the bodiless head, which is generally painted in a very fantastic manner, begins to speak, answers questions, and ends by singing a song. The trick is performed in the following way: The spaces between the legs are filled with a looking-glass; consequently, the spectators see the reflection of the curtains at the *sides* of the stage, which are made exactly like those at the back, thus giving the table the appearance of standing on three slim legs, with nothing between. Behind the looking-glass there is of course plenty of space for the body of the man belonging to the magical head. The exhibitor naturally takes especial care never to pass in front of the table, otherwise the lower part of his body would be reflected in mirrors.

The polemoscope (from two Greek words signifying "war" and "to see") is another instance of double reflection. It was said to have been invented by Hel-

FIG. 60.—The Polemoscope.

vetius, about 1637. Fig. 60 will show the principle of this instrument.

The luminous rays coming from a distant object are received upon an inclined mirror, which is elevated above the parapet of a fortification, and are reflected downwards to a second, which is placed at a corresponding angle. If necessary, lenses can be interposed, so as to give a magnified view of the distant object that is being examined. By means of such an instrument, the movements of the enemy can be followed without danger, the apparatus being generally of small size, and not attracting notice. Amongst the varieties of this instrument, is one whose use is readily seen by inspecting fig. 61, by which it seems to be perfectly possible to see with safety all that is going on outside the door of the house without being perceived. The line of the mirrors in this case is at right angles to that of the polemoscope in fig. 60. Amongst the different varieties of polemoscope which have been invented, may be mentioned a reflecting opera-glass, which was greatly used by the beaux and dandies of the last century. In the tube of this instrument was inserted an inclined mirror, which allowed the spectator to point his glass in quite a different direction to that of the object he was really looking at. In fact, it was constructed somewhat on the same principle as the Herschellian or Newtonian telescope, and enabled the possessor, while apparently enjoying the play, to observe all that was going on in the boxes or pit of the theatre. Years ago, there was a little instrument of a similar kind, sold for a penny in the streets of London, which consisted of a morsel of looking-glass set at an angle, in a pill-box, and which gave the possessor the power of seeing all that was going on behind him. Persons who wear dark preservers are often in the habit of observing all that is going on behind their backs by the reflection seen in the corner of their glasses.

Such are the principal optical recreations founded on the reflecting and refracting properties of mirrors and lenses. We shall end this chapter by appending to it the description of a few additional optical amusements that are quite within the reach of the amateur.

If the reader is in possession of a concave mirror, it may be made the means of performing a number of amusing experiments. In front of it is placed a plaster head, a skull or any other object, mounted on wheels and running along a grooved platform, which is naturally kept perfectly concealed from the spectators. The mirror is slightly inclined, so as to reflect the image of the object at an angle to the observer's eye. By running the cast backwards and forwards, it will have the appearance of advancing and retiring from the spectator in a very imposing manner. A dagger may be substituted for the cast, and by being made to work up and down on a pivot, will have the appearance of striking at the spectator. We have already seen that an experiment of this sort had such an effect on Louis XIV. that he drew his sword to defend himself from his imaginary aggressor. There is another way of performing this trick, by suddenly illuminating the skull or dagger by means of a dark-coloured box containing a light, which may be made to throw its reflections on the object, by sliding it along a couple of wires. In the case of the dagger, however, the hinged arrangement will be found more effective.

One of Robertson's tricks was called the "Magic Box," and he astonished a numerous party of visitors who were staying at a country house to which he had been invited. One of the gentlemen who was always boasting of his freedom from superstitious feelings of any kind, had had several arguments with Robertson on

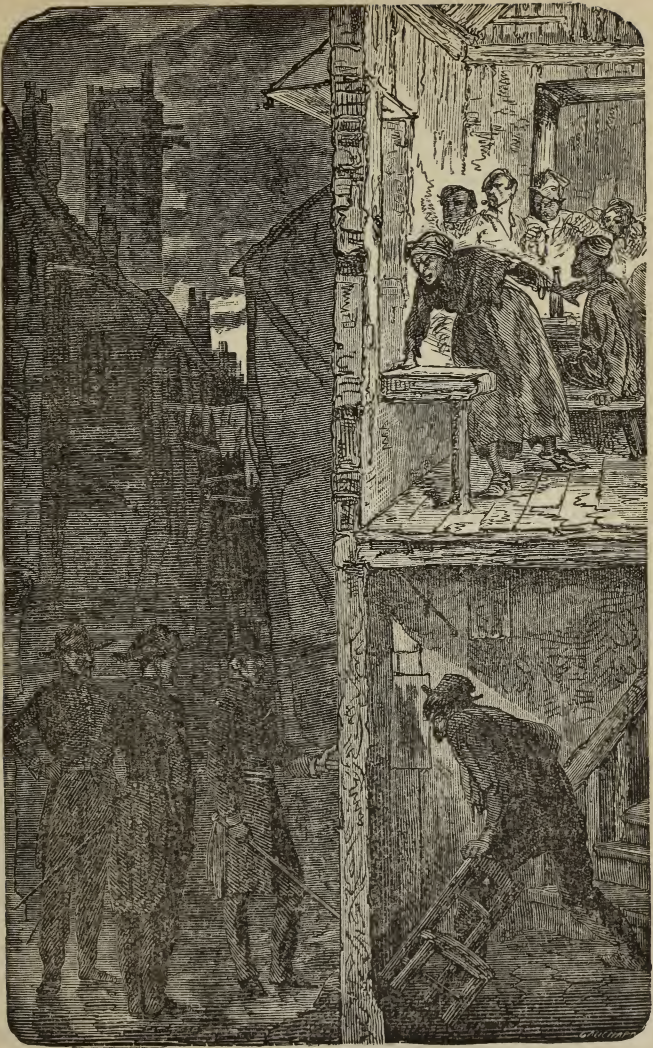


Fig. 61. — Protection against ill-natured people.

the subject of apparitions, and the latter thought that he would at any rate surprise his strong-minded friend by an easy trick or two. He consequently chose as his confederate a lady to whom the gentleman had been paying great attention during the time of his visit. Robertson one evening mysteriously delivered a small box to him, which he was to place upon his toilet table, and unlock exactly at midnight. The gentleman did so, and what was his astonishment to see the face of the lady with whose charms he had been so deeply impressed suddenly spring out of the box. His look of terror and surprise was evidently too much for Robertson's confederate, who burst into a merry peal of laughter, leaving her admirer in a very disconcerted state.

After all we have said on the subject of mirrors, it is not difficult to guess how this trick was performed. The box in question was painted black on the inside, and contained a concave mirror placed at an angle of 45°. The reflection of the lady, who was of course in the next room, was carried by means of several plane mirrors placed in boxes communicating with each other through the partition of the room, the head of the lady only being strongly illuminated, the rest of her figure not appearing by being kept quite dark.

The figures reflected from smoke are extremely surprising. To perform such experiments a phantasmagoria is necessary. The focus is so adjusted that the distant image falls just above a brasier containing lighted charcoal. Everything being ready, a few grains of olibanum or other gum are thrown on the coals, and the smoke that rises immediately affords a screen for the reflection of the images proceeding from the phantasmagoria. If the amateur is not the possessor of a magic lantern, a properly arranged concave mirror will answer almost the same purpose.

## CHAPTER IV.

### THE PROPERTIES OF MIRRORS.

ALMOST every one in his younger days has possessed and broken that pretty instrument known as the kaleidoscope. His researches into its construction no doubt taught him that it consisted of a cylindrical tube in tin or cardboard, with a moveable cap at one end and a small hole at the other. In the interior of the tube were found three long glasses, blackened on the back, placed at an angle, and kept in position by pieces of cork. The moveable cap was provided with two circular pieces of glass, one ground and the other transparent, between which were placed a number of pieces of coloured glass. On holding the instrument up to the light and looking through the eye-hole, a beautifully coloured star was seen whose form and hue changed by simply shaking the tube.

The kaleidoscope was invented by Sir David Brewster, and is exceedingly simple in principle. We all know that if a luminous object, such as a taper, is placed before a mirror, it gives forth rays of light in all directions. Amongst these luminous rays, those that fall on the surface of the mirror are, of course, reflected in such a manner that the angle of reflection is equal to the angle of incidence. If another mirror be placed at right angles to the first, and an object be put in the angle, the image of it will be multiplied four times. If the angle be diminished to 60°, six reflections will be seen, and so on. A symmetrical figure is constantly obtained, forming in one case a cross composed of four similar portions; in the other a triple star, the halves of each ray being similar. It is the symmetry of the figure that gives the pleasing effect. In the ordinary kaleidoscope the angle made by the reflecting surfaces is thirty degrees, and a star of six rays is formed, the halves of each ray being alike. The figures formed in the kaleidoscope are simply endless; and if the space between the glasses in the moveable cap be filled with bits of opaque as well as transparent substances, the varieties of light and shade may be added to those of colour. It was at one time the fashion to copy the images formed in the kaleidoscope as paterns for room papers, muslins, curtains, shawls, and other similar fabrics, but thanks to the spread of artistic taste in this country the decorative designer now relies more on his own talent than any aid he may receive from optical instruments.

Plane mirrors, as we have seen, reflect objects upright and symmetrical, reversing only the sides. Concave mirrors reverse them, and if they are not placed exactly in the proper focus, distort them by making one portion appear smaller than the other; while convex mirrors reflect them in an upright position, but also similarly slightly distorted. But when the mirror is not a portion of a sphere, like those whose properties we have been considering, the distortion is increased to so great an extent as to deform the object so that it is difficult to recognise its nature from its reflection. We all know the distortion that our face undergoes when reflected from the shining surface of a teapot or spoon, and the cylindrical mirrors that hang in the shop windows of many opticians are the source of much amusement to the passers by, whose physiognomies are shown to them either lengthened to many times their natural size, or widened to an extent that is ludicrously hideous, according to the position in which the mirror is hung. Such distortions are known to opticians as *anamorphoses*, from two Greek words signifying the destruction of form; and distorted drawings used to be sold at one time which when reflected from the surface of the cylindrical mirror, became perfectly symmetrical. Anamorphic drawings may be also made, which when looked at in the ordinary manner appear distorted, but when viewed from a particular point have their symmetry restored to them. With a little knowledge of drawing, it is not difficult to produce these in great variety.

Suppose the portrait in fig. 62 to be divided horizontally and vertically by equidistant lines comprehended within the square A B C D.


Fig. 62.

Upon a second piece of paper draw the figure shown in fig. 63 in the following manner. Draw the horizontal line *a b* equal to A B (fig. 62,) and divide it into the same number of parts. Through the centre draw a perpendicular line to V, and cross it by a line *e d* parallel to *a b*. Lastly, draw V S horizontal to *e d*. The length of the two lines *e* V and S V is quite arbitrary, but the longer you make the former in proportion to the latter the greater will be the distortion of the drawing Now draw the lines V 1, V 2, V 3, and V 4, and join S to *a*. Wherever S *a* crosses the divisions 1, 2, *e* 3, 4, and *b*, draw a horizontal line, parallel of course with *a b*. You will thus have a trapezium *a b c d* divided into as many spaces as the square A B C D in fig. 62, and it now remains to fill them in with similar portions of the figure. Thus, for instance, the nose is in the fourth vertical division, starting from the left, and in the third and fourth counting from the top; in order, therefore, to make it occupy so lengthened a space it must be considerably distorted by the pencil. It will be readily seen also that the more numerous the spaces into which the square is divided, the easier it will be to draw the distorted picture. It is by this means that the *anamorphosis* shown in fig. 63 has been drawn.

The next thing to do is to find the point of view from which we can see the figure in its natural proportions. This will be found to be at a distance above the point V equal to the line V S. In order to complete the experiment it is simply necessary to place the distorted picture in a horizontal position, and fix a piece of cardboard vertically at the point V. If a hole be punched in it at a distance from V equal to S, and the drawing be looked at through it, the whole of the parts will fall into symmetry immediately.

The experiment may be tried first with fig. 63, the hole being made rather large, and the eye placed at a distance of from 3 to 4 inches.

It would be difficult, without having recourse to geometrical formulæ, to explain how it happens that by placing the eye at a particular point the distorted lines of the drawing become symmetrical; but perhaps a mechanical demonstration will help to make this difficult subject a little plainer.

Draw in outline any figure upon a piece of cardboard, and make a series of pin-holes along the most prominent lines of the drawing, taking care that they are pretty

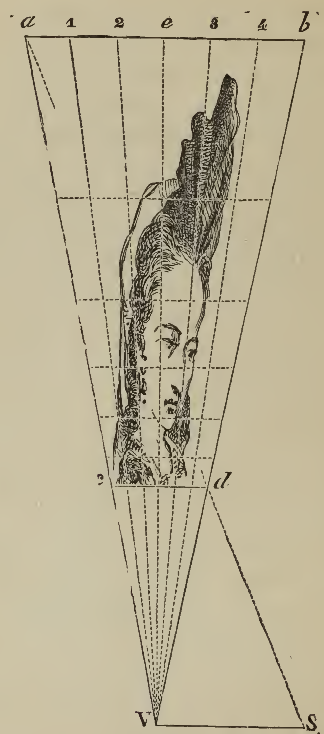



FIG. 63.—Anamorphosis.

close together. Place the perforated card in a vertical position on a sheet of paper, so that the rays from a candle or lamp may fall, on the flat surface beneath. On looking at the luminous figure formed from the drawing, you will find that it is as much distorted as the lady's head in fig. 63, and that the lower you place the candle the greater will be the deformity. You may if you please, trace the luminous figure on the paper, and the result will appear distorted when looked at in the ordinary manner, but symmetrical when viewed from the point at which the flame of the candle was placed.

In the foregoing experiments we have spoken of the anamorphic drawings as being placed in a horizontal position, but they may be looked at just as well vertically, the card with the hole being in this instance horizontal. It is also not necessary that the point of sight (v, fig. 63) should be in the centre of the picture; it may be placed at one side or the other, care being taken to draw all the divisional lines so that they meet at this particular spot. A few experiments with a candle and a perforated figure will soon show the student how to accomplish this.

Anamorphoses by reflection may be prepared, if this principle is carried out, which appear a mass of confused lines until they are reflected in a cylindrical mirror. Formerly opticians were accustomed to construct anamorphoses which became symmetrical pictures when viewed in a conical mirror; but the fashion for such toys appears to have gone out. Such drawings were extremely difficult to make, and the mirrors, having to be ground and polished with great care, were very expensive.

Some experimentalists have carried the subject so far that, by looking at the drawing of an object in particular positions, it changed into quite a different subject. In the cloister of an abbey that once existed in Paris, there were two anamorphoses of this kind. They were the work of a certain Father Niceron, who has left behind him a treatise in Latin on optical wonders, entitled *Thaumaturgus Opticus*, which contains a long essay on anamorphoses. One of these pictures represented St. John the Evangelist writing his Gospel; the other Mary Magdalene. When looked at in the ordinary manner, they appeared to be landscapes; but when the observer placed himself in a particular position, they changed into the figures we have mentioned.

## CHAPTER V.

### CHINESE SHADOWS.

WHILE upon the subject of optical wonders, we should hardly be forgiven if we did not give a description of the amusement known as Chinese shadows, or Fantocini. In the winter time it is difficult to pass through any of the large thoroughfares of London after nightfall, without seeing a crowd admiring the popular fantocini farces of the "Broken Bridge," or "Billy Button;" and although these dramatic exhibitions are not always free from vulgarity, they are received with vociferous applause by at least the younger portion of the audience.

The apparatus for the exhibition of the fantocini is generally very simple. The screen on which they are shown is generally made of calico rendered semi-transparent with copal varnish, and the figures are cut out of cardboard. Frames containing landscapes and scenes of different kinds are also provided, which are cut out in the same material. The *dramatis personæ* are generally made with moveable limbs, which they throw about in the most unanatomical manner, and the showman is often endowed with ventriloquial talents of no mean order. This amusement is to be found in all parts of the world, from the Strand and Tottenham Court Road London, to the streets of Algiers and Java. A graphic writer in the *Magasin Pittoresque* gives a pleasant description of the fantocini, as exhibited at the Arabs' theatre in the Mohammedan quarter of the city of Algiers. It was on the occasion of the feast of the Bairam, which immediately follows the termination of the Ramadan, or Mohammedan Lent. The theatre, which was the only one frequented by the Arab population, consisted simply of a long vaulted hall, without seats, boxes, or galleries; but the audience, who had already been there some time, did not seem to regard the omission as of any consequence, but had seated themselves on the ground with great coolness, chatting in whispers, and waiting patiently until the director should consider the place full enough to begin the performance. Half an hour elapsed, and the spectators still chatted on quite unconcernedly; an hour, and yet there was no hissing or stamping of feet from the grave and patient spectators. At last they reached the maximum, and a boy came forward and blew out the few lamps with which the theatre was lighted, leaving them to smoulder away with a perfume that was certainly not Oriental in its character. First came the legend of the Seven Sleepers; then Scheherazade relating her bewitching stories to the Sultan. These were followed by Aladdin and the Wonderful Lamp, a story that is as popular in Algiers as it is in London or Paris; the whole culminating in a kind of burlesque, in which a great deal of gross fun was mixed up with a number of rebellious allusions. The devil, for instance, who is of course one of the members of the troupe, is portrayed as a French soldier, bearing a cross on his breast like an ancient Crusader. After him came Carhageuse, who is the buffoon of the Eastern stage, and who makes violent but unsuccessful love to a charming young Jewess. There was a poor barber who was raised to the dignity of grand vizier, his successor's head being cut off by the yataghan of the Oriental Jack Ketch, to the great de-

Fig. 64.—Effect of cut paper-work.

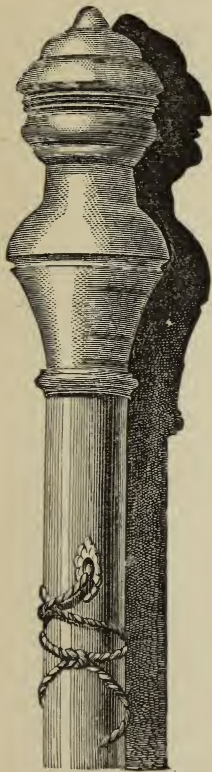
light of the people. Then a wretched Jew receives the bastinado, amidst vociferous applause, which increases still higher when the ears of an unhappy Giaour are cut off and thrown to the dogs. Throughout the piece, it is of course the Mussulman who always triumphs, like the French guards at the *Cirque Impériale*, or the British grenadiers at old Astley's. The performance concluded with a grand naval battle between the Moorish and Spanish fleets. The drum as usual served for cannon, there was a great deal of smoke and confusion, and the Christian fleet gradually sank under the continuous fire of the Mussulmans amidst the plaudits and bravos of the crowd.

In Java, the subjects of the fantocini are generally taken from the native mythology. The screen on which the shadows are exhibited is ten or twelve feet long, and five feet high, and the figures are cut of thick leather, their limbs being moved by thin pieces of nearly transparent horn.

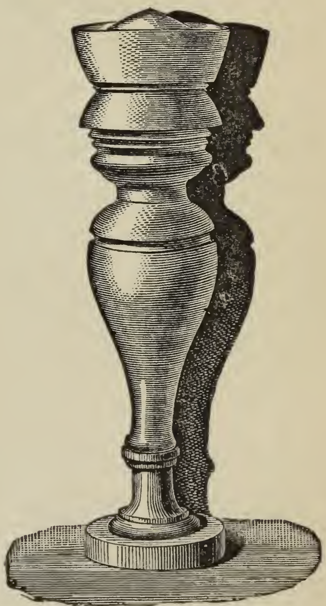
In fig. 64 we see another kind of Chinese shadows, in which the lights of the figure are cut out. These pictures are perfectly unrecognisable as being even the basest imitation of any known form; but when their shadows are thrown on the wall, the cut-out portions show us lights, whilst those that have been left form the shadows. On the Boulevard des Capucines, at Paris, there used to be a man who managed to pick up a good living by selling these candle shadows. Of course he used to carry on his trade of an evening, and with a strong lamp he would throw the shadows of his figures on the white walls of the houses, or the blind of a shop window, or even on the pavement. With a little care and ingenuity a number of these amusing cards may be easily designed. In showing them, care must be taken to choose the best distances between the light and the paper, and between this latter and the wall.

If the card be placed too close to the wall, the resulting shadows will be too dark, and the outlines too sharp; if, on the contrary, the light is placed too far off, the outlines become confused, and the proper effect is lost.

Shadows have been applied before now to the propagation of seditious ideas. "In 1817," says an esteemed French author, "one winter's night we were all sitting round the table listening to my father, who was reading aloud an interesting book of the period, when a friend of our family, who had been formerly an officer of the Empire, entered the room. He was a serious, upright, soldierly man, and wore his coat buttoned up to his chin. He had hardly replied to our salutations, when he drew a chair to the table, and made a sign with his hands and eyes that plainly indicated silence and discretion. There was something in the expression of his countenance that seemed to show that he had something mysterious in store for us, and we fully expected to hear some extraordinary news, or to see him bring out a Bonapartist pamphlet of more than usual importance. Our surprise was consequently great when we saw him slowly unscrew the top of his cane, which was turned out of boxwood, and presented nothing very remarkable either in form or material. He, however, took up a copybook which was lying on the table, placed it at a certain distance from the lamp, and then laid upon it the little piece of turned boxwood. At first we noticed nothing at all extraordinary, and he smiled at our want of intelligence, until at last my youngest brother cried out suddenly, 'Look! there's the head of Napoleon!' and truly enough, we found, on looking more attentively at the shadows of the turned knob of the cane, that their profile was that of the great exile, most correctly and clearly portrayed. The old captain's face lighted up at the sight, and the tears came into his eyes. 'We shall see him again,' he murmured in a low voice, and he hummed the burden of a Bonapartist song then in vogue. During the rest of the evening he was very



Cane.



Seal.

FIG. 65.—Seditous Toys.

lively, and proved to us most conclusively, that before six months the *Grande Armée* would be revenged for their defeat at Waterloo. Some weeks after, there was hardly a soldier in the town that did not possess a stick or a tobacco-pipe stopper, turned in this fashion, but one day a panic seized everybody, and the canes and pipe stoppers were all burnt."

Fig. 65 represents historic heads cut in this way. During the Shakespeare Tercentenary excitement, a London turner made quite a little fortune by making heads of the great poet on the same principle.

# CHAPTER VI.

## POLYORAMA—DISSOLVING VIEWS—DIORAMA.

The description of the polyorama naturally follows that of the phantasmagoria, being a practical application of precisely the same principles. In the case of the polyorama, however, two or even more lanterns of the best construction, are used. There are therefore two sets of lenses identical in every particular, placed side by side, in the same line, the foci of both being adjusted for the same spot, so that the images refracted from each may superpose each other without difficulty. In each instrument there are the same pictures, but they differ in certain particulars, as we shall see presently.

In the phantascopes shown in figs. 52 and 54 there are two sets of lenses; the first carries a glass bearing the image of a skeleton in a winding sheet, while on the glass belonging to the second a naked skeleton is portrayed. If, therefore, at a given instant the first lantern is shut off, the spectators see the winding sheet torn, as it were, suddenly from the spectre before them. The first lantern being turned on once more, the skeleton is instantly reclothed in its hideous garb.

It is of course not necessary always to choose such horrible subjects for representation, as it is possible to produce changes of a much more agreeable nature. For instance, a volcano may be depicted during its tranquillity, with the sun shining on its verdant sides, and surmounted with a gently rising wreath of smoke. Then it may be shown at night, with its crater vomiting flames and red-hot stones, while streams of lava are flowing beneath. By proper mechanism, one lantern may be gradually shut and the other as gradually opened, producing an effect that appears perfectly natural, from the gentle change which takes place. Daylight, twilight, and moonlight effects may be easily made to succeed each other in their proper order, and the most opposite scenes may be made to change each other by proper appliances. Those who have seen the dissolving views at the Polytechnic, know what effects are produced by this very simple means. A virgin forest changes to a crowded church, which in turn dissolves into a scene on the Alps.

The diorama, properly so called, invented by the illustrious Daguerre, differs completely in principle from the apparatus we have just been describing. As its etymology indicates, the pictures shown are seen *through*. As in the case of the polyorama, there are two different effects painted upon the cloth, which are brought out by a double system of illumination.

Fig. 66 will show the way in which these changes are managed. The large picture, which is hanging vertically, is painted both in front and behind. The front is illuminated by reflection from a semi-transparent screen placed over it, which receives the light of the floor above. The back is lighted from the windows behind, which are provided with blinds to regulate the amount of light. The effects produced by the diorama were truly marvellous, and Daguerre had a special talent for this kind of painting. His famous *Midnight Mass*, which was exhibited at the Regent's Park, was one of the most renowned of his works. The scene first represented a dark, empty church, feebly lighted by a

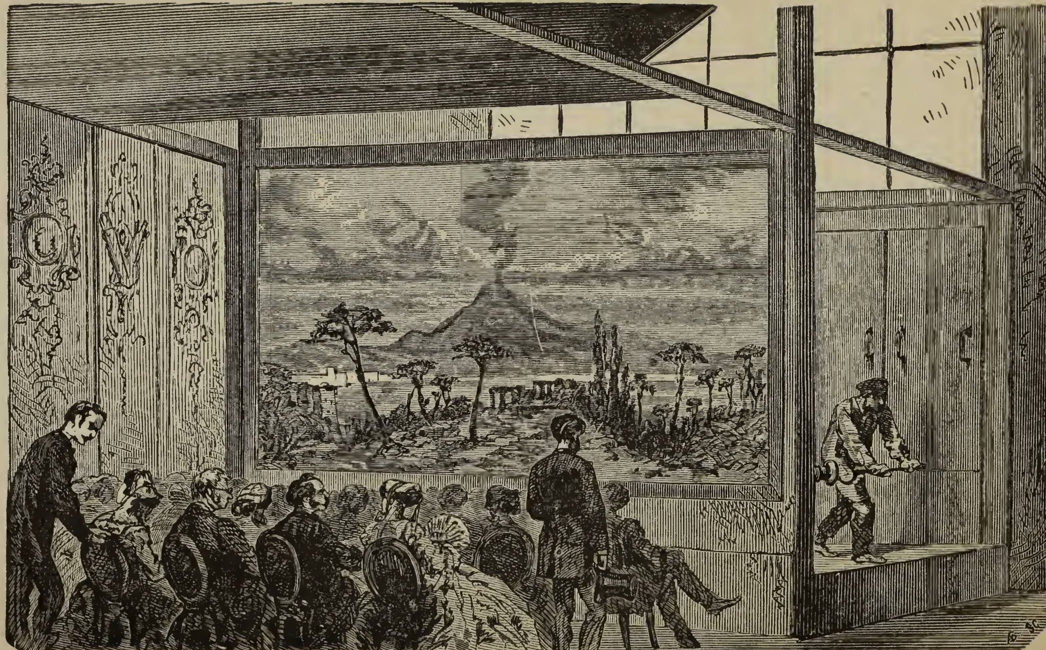


Fig. 66.—Diorama.

small altar lamp, but gradually the lights appeared here and there, worshippers congregated in front of the altar, filling the nave and aisles. In Paris the same scene was exhibited, representing the interior of the Church of St. Germain l'Auxerrois with such perfect reality, that a countryman actually threw a halfpenny against the painted canvas, to see whether he were really in a church or not.

The next scene represented the destruction of the village of Goldau, near Lucerne, by a landslip. First there appeared a smiling fertile valley, its sides crowned with verdure; a storm gradually rose, the rain fell, the wind blew, the lightnings flashed, and the thunder rolled in the distance. Darkness at last closed in, and when the sun once more rose over the valley, nothing was to be seen but a mass of fallen rocks.

## CHAPTER VII.

### THE STEREOSCOPE.

Having devoted so much space in the preceding chapters to optical amusements of a purely recreative character, it is only right that we should now say a few words on certain instruments of a less frivolous character than those we have lately been considering, and which deserve at our hands the most serious attention. We shall, therefore, in the present chapter, speak of an ingenious instrument which serves to show in relief the images of objects depicted on a flat surface. We have already seen, that although we have two eyes, provided with lenses and screens by means of which the images of things around us are formed, we only perceive a single object; and the student has no doubt long since wondered why nature has bestowed two eyes upon us, when only one would have apparently served the same purpose. This question was for a long time a complete puzzle to philosophers, and it was not until Professor Wheatstone made his experiments on binocular vision in 1838, that the matter received a satisfactory explanation. He showed that each eye receives a different impression of any object upon the retina, and that it is in consequence of the union of these slightly dissimilar images that the sensation of relief is experienced. A one-eyed man or a Cyclops would only partially perceive relief in the objects presented to his view, in consequence of a single image being sent to his brain. He would, no doubt, after examining the things he saw with his hands, know they were solid, and generally see them so; but if a new object were presented to his view he would have some difficulty in knowing whether it had a flat surface or not.

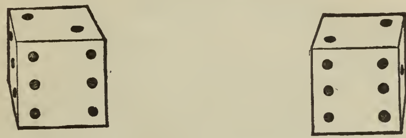


FIG. 67.

The principle of binocular vision may be explained as follows: If a playing die, such as is represented in fig. 67, be held out at arm's length in the position indicated in the figure, and looked at first with the left eye and then with the right, we shall find that in the first case we see a little of the three dots on the left-hand side, and in the second we lose sight of the three dots and see a little of the single one on the right-hand side. The images seen by each eye are, therefore, slightly dissimilar, and it stands to reason that, if by any means we can combine two slightly dissimilar flat pictures of a solid object, we shall see it in relief. This was proved practically by Professor Wheatstone, who constructed an instrument capable of effecting the desired union, and which has since been called the stereoscope, from two Greek words signifying 'to see solid.' The instrument remained for a long time fallow, so to speak, from the difficulty of drawing two pictures that should be identical in size and details, although dissimilar in the arrangement of their perspective. It was, therefore, not until photography enabled us to do this with the greatest ease and exactitude that the stereoscope became common. The instrument first devised by Professor Wheatstone, was what is termed a reflecting stereoscope, and was expensive to make and cumbrous to use. It was

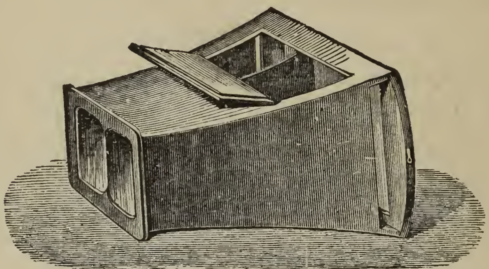


FIG. 68.—Stereoscope.

modified by Sir David Brewster, by the substitution of prisms for reflectors, and was thus made cheaper and more portable. The refracting form of stereoscope is so familiar to most people, that it really needs no description. It will only be necessary to mention that the prisms used in the eye-pieces are made by cutting a double convex lens in two, and reversing the halves. They are so placed that the centre of each prism is just in the centre of each eye; but as the eyes of different people vary in distance, an arrangement is generally added so that the eye-pieces may slide from side to side. Being cut from lenses, the prisms have a magnifying power; consequently other means are provided for sliding them up and down to suit the length of focus in different eyes.

In fig. 69 we can follow the path of the rays proceeding from each picture, and reach the eyes apparently from a spot exactly between the two.

In the reflecting stereoscope two mirrors are joined together at right angles to each other, the two pictures being placed at each side, at a distance corresponding to their size. The reflecting instrument, although not

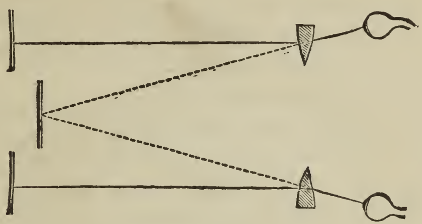


FIG. 69.—The Principle of the Refracting Stereoscope.

so portable, is in some sort superior to the other, inasmuch as pictures of any size can be seen by it, whilst in the smaller instrument the size of the photograph is limited by the distance at which the eyes are placed.

It should be mentioned, that no optical instrument of any kind is absolutely necessary to obtain a stereoscopic effect from two suitable drawings or photographs, as it is quite possible by a little management of the eyes to cause the two images to combine with each other. Referring again to fig. 67, it will be perceived that the two figures of the dice are about an inch and a half from each other. Holding the book at about ten inches from the eye, they are viewed by squinting strongly until the *right* eye looks at the *left* die, and the *left* eye at the right. This may be also done by converging the eyes on a point beyond the centre of the figure, which may be easily done by looking at a point midway between the two. In both cases the images at first appear doubled, and we see four dice, but a little practice will soon enable you to cause the two inside images to coalesce, and so give the effect of relief. It is true that even then three images are seen, but the eye soon grows accustomed to neglect them altogether. This habit is a very pleasant acquirement for the London *flâneur*, who can thus see in perfection the numberless stereoscopic views now shown in our shop-windows without the intervention of an instrument of any kind.

The method of photographing subjects for the stereoscope is very simple, and consists in taking two views of the object to be depicted, from two different points. According to the distance of these points from each other, so will the resulting pictures appear in greater or less relief. This is readily seen in some stereoscopic portraits which have been taken at a large angle, and consequently show such increased relief as to produce distortion. Theoretically, the interval of the two points of view ought to be two inches and a half, that being the average distance between the two eyes; but in practice it is better to increase it in the case of portraits or other near objects to about twelve inches, and in that of views to even several feet. Brewster's original rule for taking stereoscopic photographs, was to place the cameras one foot apart for every twenty-five feet of distance. The beautiful stereoscopic pictures of the moon photographed by Mr. Warren de la Rue were taken at more than 1,000 miles' distance, in order to obtain the necessary relief. The principle of the stereoscope has received many useful applications in the way of book illustrations, art teaching, and anatomical demonstration, and has thus gained a position among philosophical instruments that it did not at first possess.

A combination of the principles of the phenakistiscope (fig. 4) and stereoscope, has resulted in the invention of an instrument called the stereotrope. A number of binocular photographs of some object in motion—a steam-engine, for instance—are taken when the moving parts are in different positions, and mounted on two revolving discs, the images being combined by means of a pair of semi-lenses, as in the ordinary refracting stereoscope.

We cannot leave this subject without describing the pseudoscope, also the invention of Professor Wheatstone. If a stereoscopic pair of photographs of some solid body—a ball, for instance—are mounted the reverse way, that is to say, if the picture intended to be looked at by the right eye is placed on the left, the relief of the object will be reversed, and the ball will appear as a hollow hemisphere. If, therefore, we can by means of lenses or prisms cause the image of any natural obje t, as seen by the right eye, to be conveyed to the left, and *vice versâ*, we shall see the relief reversed. A conical cap will appear in relief as a cone, a globe will look like a hollow sphere, and the human face will take the semblance of the inside of a mask. The same deception may be effected by looking at a seal through a short-focused lens, so that the image shall seem reversed. In this case, the light coming apparently from the wrong side, and shining on the parts in relief, gives them the appearance of being hollow. An intaglio will, of course, appear in relief when so looked at. Photographs of gems and bas-reliefs will also present a pseudoscopic appearance, if looked at in a light coming from the opposite side to that in which they were taken. The same appearance may be seen sometimes in wall papers having patterns painted in strong relief.

## CHAPTER VIII.

### THE CAMERA OBSCURA AND CAMERA LUCIDA.

The construction of the camera obscura is founded on the fact that the rays of light, when collected into a point either by being passed through a small hole or a converging lens, form an image of the objects from which they proceed at the point of meeting. This may be readily tried by piercing the shutter of a room with a small hole, and holding a piece of paper within a short distance of it. It will be noticed that the smaller the hole the more distant will be the image formed. The first person who observed this fact was John Baptist Porta, an Italian philosopher who lived in the latter part of the seventeenth century. He noticed that when a screen was placed opposite a small hole in the shutter of his room, the objects outside were depicted on it in a reversed position with moderate distinctness; but that when a biconvex lens was placed over the hole, the picture was rendered much more distinct. This was the first attempt at the formation of the camera obscura, an instrument that has since bestowed such incalculable benefits on humanity.

The shape of the images so formed is independent of the shape of the opening, which, as long as it is sufficiently small, may be square, oval, or triangular. This may be easily seen when the sun shines through the intervals between the leaves of a shady avenue or bower

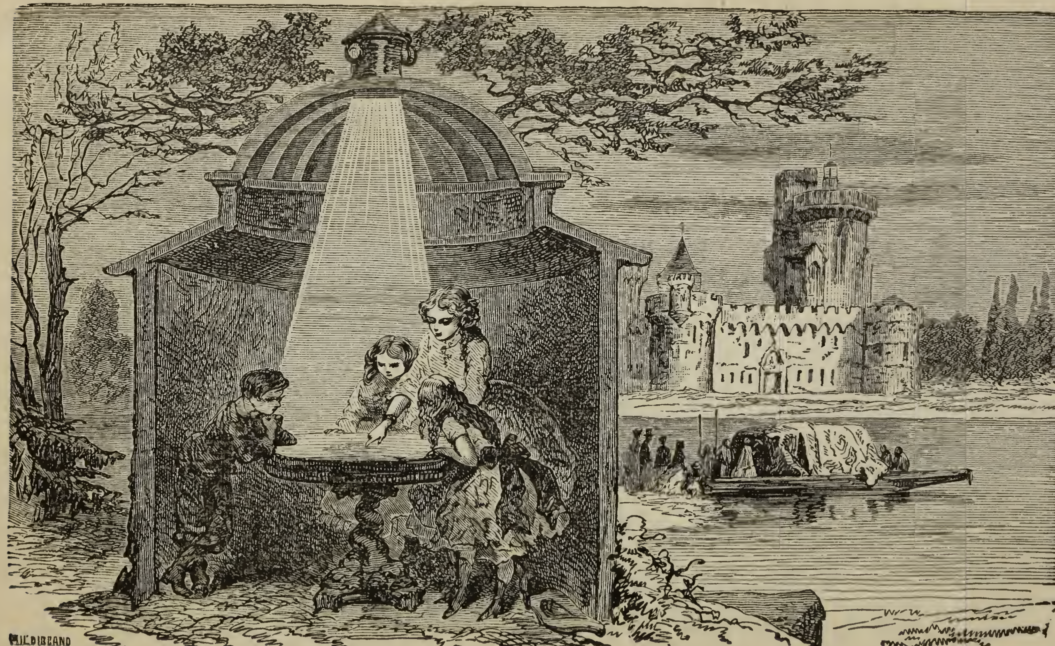



Fig. 70.—The Camera Obscura.

of trees. The image of the sun as a circular patch of light is seen scattered over the surface of the ground, although the accidental intervals formed by the leaves above were of a thousand different shapes. These images at the time of an eclipse of the sun are very surprising, taking, as they do, the form of a crescent, more or less large according to the magnitude of the eclipse.

This property possessed by the rays of light, of depicting on a screen the forms and colours of the objects from which they proceed when passed through a small aperture or a lens, is taken advantage of in most places famous for their natural scenery. The apparatus employed for this purpose is comparatively simple, consisting merely of a dark wooden hut, with a whitened table in the centre, and a mirror and lens in the apex of the roof. In fig. 70 we have a section of a camera obscura of this kind. The mirror and lens at the top of the apparatus are made to revolve, so as to bring every part of the landscape into view in turn. A camera obscura in a position commanding a view of moving objects, such as ships sailing to and fro, or the busy streets of a populous town, is an unending source of amusement, and may be easily and cheaply constructed.

The camera obscura has been much utilized for taking hasty but exact sketches of various places. For this purpose it is made very light, and mounted on three legs carrying at their junction a flat table, whereon is placed the paper to receive the drawing. The tripod is covered with a black curtain, which, falling over the artist, effectually excludes all the rays of light except those which pass through the lens and are reflected downwards by the mirror. In the better kind of apparatus the mirror is replaced by a prism, which throws a clearer image than a mirror upon the screen.

It is on these properties of the camera obscura that the art of photography was founded. Everybody who saw the beautiful images formed by this instrument was struck with the idea that by some means or other they could be fixed on paper. After numberless attempts the long-wished-for goal was at length arrived at; and now optics, aided by chemistry, is enabled to depict for us natural objects of every kind, from the distorted limb of the hospital patient to the beautiful forms of the queens and empresses of the world—from the tiniest animalcule to the great sun itself, who is compelled by the might of science to paint his own portrait for us with all his faults and imperfections.

The lenses used for photographic purposes have only reached their present state of perfection after ceaseless labours of the philosophers and opticians of all countries. At first only a single lens was used, but it was found that the rays which exercised a chemical action did not meet in the same point as the rays of light, for it must be remembered that it is not the light we see that acts upon the substances used in photography, but another influence, known as actinism. It was also found that a single lens would not give a flat picture when the whole of its aperture was used, the edges of the image being always blurred and indistinct. This latter defect was found to be partially obviated by decreasing the opening, but this remedy shut off the light and prolonged the process. Gradually these two defects were removed, and now every photographer, no matter how humble, is possessed of a lens capable of taking a clear picture, every detail of which is perfectly distinct and faithful.

The camera lucida bears a great analogy to the camera obscura in the purpose for which it is used, though not in the principle on which it is constructed. It is employed, like the preceding instrument, for obtaining faithful copies of a landscape, a building, or even of another drawing. It was invented by Dr. Wollaston, in 1804, and consists of a little four-sided prism, of which fig. 71 is a section.

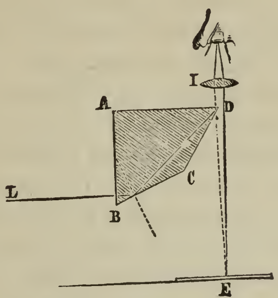



FIG. 71.—Section of Camera Lucida.

The angle at A is a right angle; the angle B measures $67\frac{1}{2}°$, the angle C 135°, and the angle D is, of course, equal to B. It is mounted on a sliding foot, so that it may be raised or lowered at will, or turned in a horizontal direction. The path of the rays in this case is easy to follow, the object to be copied being placed at L, and the eye at I. On looking downwards the image of the object to be drawn is seen on the paper; and if the eye is placed so that the edge of the prism will just cut the pupil in two, the paper and pencil will be seen at the same time. It will be seen from the diagram, that the rays proceeding from L strike on the surface A B at right angles, and, being then reflected from C B, pass upwards again to point E. The direction of the rays is in reality a little more complicated than this. In the case of distant objects it is impossible to see both the object and the pencil at the same time; a lens is sometimes introduced at I to modify this defect. The original instrument has also been modified by the introduction of a triangular prism, in conjunction with plates of coloured glass, but the difficulty of rendering the image and the paper of the same strength is very great. The instrument is also hard to use, from the additional difficulty of always keeping the head in the same position, for the least movement from left or right is sufficient to throw the whole drawing out.

A simple camera lucida may be made out of a small piece of looking-glass, mounted at an angle of 45°, or half-way between the horizontal and the perpendicular. If this be turned towards the drawing or view to be copied, and the left eye applied to the mirror, the image of the object will be seen on the paper below, and the pencil may be guided with the right. The proper use of this simple little instrument depends in a great measure upon the focus of each eye being the same. The light falling on the paper, too, requires very careful adjusting, otherwise the brighter object will eclipse the other. It is a good plan, too, to whiten the pencil or pen used, so that it may not so easily be lost when drawing the brighter parts of the object. We have seen excellent drawings made from plants by means of a little instrument of this kind, which simply consisted of a piece of looking-glass inserted in a cork stuck in a glass bottle.

# CHAPTER IX.

## THE SPECTROSCOPE.

We now come to speak of an instrument which may fairly rank, after the telescope and microscope, as one of the most wonderful discoveries of modern optical science. By its means we have not only discovered four new elementary bodies, which are found in certain minerals in inconceivably small quantities, but we have also determined the chemical composition of some of the remotest stars and nebulæ.

In 1701 Newton discovered that if an ordinary ray of white light was admitted through a small hole into a dark chamber, and thence passed through a triangular prism, it became decomposed into a coloured band, known as the solar spectrum. As we have already explained that this decomposition is caused by the different coloured rays that make up white light being bent unequally by the action of the prism, we trust the following explanations will be readily understood. In 1802 Dr. Wollaston, an English philosopher, discovered that by using a narrow slit, instead of a round hole, the resulting spectrum was no longer continuous, but was divided at intervals by dark lines extending across it in a direction parallel to the edges of the prism. These lines attracted considerable attention at the time, but it was not until 1815, that Fraunhofer, an optician of Munich, investigated them with accuracy. He mapped and counted no less than six hundred of them, identifying eight of the most conspicuous by the first eight letters of the alphabet. Their positions are as follow:—

| | | | |
|---|---|---|---|
| A. | Beginning of red. | E. | Middle of green. |
| B. | Middle of red. | F. | Beginning of blue. |
| C. | Beginning of orange. | G. | Middle of indigo. |
| D. | Middle of yellow. | H. | Middle of violet. |

The designations of these lines have been retained to the present day, and they have been named after the Munich philosopher, being known as Fraunhofer's lines. They are to be seen in all parts of the spectrum, and increase in number and fineness according as the width of the slit through which the light passes is diminished. It may be asked, how it happens that they increase in proportion to the narrowness of the aperture admitting the light? A little consideration will soon show the reason of this.

When a beam of light is passed through a hole of, let us say, the eighth of an inch in diameter and decomposed by a prism, the spectrum so produced is imperfect, inasmuch as an infinite number of spectra are thus superposed, and for this reason, that the rays of light entering on the right side of the aperture will give a spectrum falling in a different place to that formed by the rays entering on the left. In order, therefore, to diminish the confusion caused by the superposition of a number of spectra, the aperture ought to be reduced to a narrow slit. When the thin slice of light passing through the slit is decomposed by the prism, we find that not only is the purity of the colours greatly increased, but the lines in question make their appearance more or less in all parts of the coloured band.

These lines are very unequally distributed, some being crowded together in masses, while others are extremely faint, and are separated by large intervals. Their position is well marked and determined, no matter from what source we obtain our beam of sunlight. Whether the spectrum be produced from the sun itself, or from the reflected light proceeding from the moon or planets, they are still found in the same place; only that in the latter case they are not so numerous, on account of the light being much fainter. For many years the cause of these lines remained a complete mystery, and it was not until Bunsen and Kirchhoff undertook their investigation that a satisfactory explanation of their origin was arrived at. In order to explain this, we must consider briefly the properties of the spectra of flames, and other luminous bodies.

If, instead of the light of the sun, we examine prismatically the light given off by an incandescent body, such as a white-hot piece of platinum, we shall find that the lines seen in the solar spectrum are absent, and that we have a continuous band of coloured light quite uninterrupted by dark spaces or bands. The same absence of lines is seen in the spectra of the electric light and the flame of an ordinary candle, the light in each of these cases being produced by particles of carbon in a state of vivid incandescence. But if we examine the flame of incandescent gases, we shall find a spectrum of an entirely new kind. Thus if we examine an ordinary gaslight through a slit with a prism, we shall obtain a continuous spectrum, in consequence of the luminous portion of the flame consisting of solid carbon in a state of incandescence; but if we turn down the flame, so as to lessen the amount of carbon to be burned, we shall find the whole of that body is converted into feebly luminous gas, giving off a faint reddish blue light. If we now again examine it in the same manner, we shall find that the spectrum produced consists of black spaces, here and there crossed by a few faint coloured lines or bands. The reason of this is obvious: in the faint flame caused by the carbon and hydrogen in a state of luminous vapour, which only have a few of the colours of the spectrum, which, when passed through the prism, fall into their proper places. All substances with which we are acquainted are capable of being converted into luminous vapour by means of heat, and when thus burnt produce flames of more or less faint luminosity, generally characteristically coloured. A piece of soda inserted in the wick of a spirit lamp gives a yellow tinge to the flame; a morsel of saltpetre (nitrate of potash) or nitrate of strontia will give a purple and crimson tint respectively. These hues are caused by the metals sodium, potassium, and strontium contained in these salts being converted into luminous vapour. On analyzing these coloured flames with a prism, as before, we should find in the case of the soda a single broad yellow line, situated just in the middle of the yellow portion of the spectrum, the rest of the space where the spectrum should be being perfectly dark. The reason of this is pretty simple. Sodium burns with a pure yellow flame, consequently when passed through a prism it cannot split into any other colours, but takes its place in the position belonging to yellow of that particular hue. Were it a little more orange or green in tint, it would take its place nearer to the red or violet end of the spectrum. The light from saltpetre, which contains potassium may next be examined. It will be found to tinge the flame with the spirit-lamp of a beautiful purple. We can almost guess what will happen when this flame is submitted to the action of the prism. We shall find that the purple light emitted will split into red and violet, which will immediately arrange themselves in their proper positions according to their hues. If in like manner we substitute nitrate of strontia for saltpetre, we shall get a splendid crimson flame which is decomposed by the prism into red, orange, or blue.

On submitting the compounds of the other elements to the same tests, we shall find that each of them, when converted into luminous gas, is capable of producing coloured lines of various kinds when the light of their flames is passed through a prism. If, therefore, we had a number of salts of whose composition we were ignorant, all we need do is to burn them in a spirit-lamp, and by the number and position in the lines of their spectra we should be able to tell immediately of what they were composed.

The spectra of nearly all the elements capable of being connected with luminous gas have been determined with great accuracy. Perhaps the number and position of the lines of a few spectra will be interesting to the student.

*Sodium.*—This is the metallic base of soda salts, and gives a double bright yellow line in the middle of the yellow.

*Potassium.*—The base of the various salts of potash. It gives one line in the extreme red, one in the middle of the red, one in the violet, and a peculiar glow in the centre of the spectrum.

*Strontium.*—The base of the strontia salts, of which the nitrate is used as the principal ingredient in the red fire of the theatres. It gives a group of lines in the red and orange, and a beautiful blue one in the middle of the blue.

*Barium.*—The base of the baryta salts, one of which is used in making green fire. It gives several strong lines in the green, and a few in the red, orange, and yellow.

After the position of the spectral lines of most of the elements had been discovered, Messrs. Bunsen and Kirchhoff were one day examining the saline deposit of a spring which issues from the earth near Durkheim, in the Palatinate, and were surprised to find that a blue line belonging to no known metal made its appearance in addition to the potassium, sodium, and other lines produced by the saline ingredients of the water. These philosophers immediately concluded that the unknown line was caused by an unknown metal, and they at once set to work to obtain a larger quantity of the saline residue from the spring. They evaporated down no less than forty tons of water, and succeeded in isolating the new substance, which turned out to be a metal resembling potassium. While examining the residue more carefully, a new, dark *red* line, beyond that belonging to potassium, was discovered, pointing to the existence of a second new element, which was also afterwards obtained in the pure state. These two new metals, which closely resemble potassium in their properties, were named in accordance with the lines given by them when converted into luminous gas. The first was called cæsium, from *cæsius*, Lat. light blue; and the other, rubidium, from *rubidus*, Lat. dark red. Since the publication of MM. Bunsen and Kirchhoff's experiments, these two elements have been found in comparatively large quantities in various minerals, and these properties have been closely studied.

Spectrum analysis has yielded us two more new metals since first these philosophers applied the prism to the determination of the chemical composition of various bodies. Mr. W. Crookes, F.R.S., an English chemist of eminence, while examining the flame of a deposit obtained during the manufacture of sulphuric acid from a certain sulphur mineral found in the Hartz mountains, perceived a brilliant green line with which he was previously unacquainted, which quickly flashed into view, and then disappeared. After numerous experiments on various other minerals (for the deposit he had first experimented upon only yielded him a few grains of the new body), Mr. Crookes succeeded in discovering a comparatively large quantity of it in a sulphur mineral found in Belgium. The new element was found to be a heavy metal, closely resembling lead in its properties. It was named by the discoverer, thallium, from the Greek word *thallos*, a green twig, from the brilliancy of the single green line that indicates its presence. In like manner, Messrs. Reich and Richter have discovered a fourth new metal, which has been named *indium*, from its principal lines being found in the centre of the *indigo* of the spectrum.

The delicacy of spectrum analysis may be imagined from the fact that a quantity of sodium amounting to less than the *two-millionth* of a grain can be detected by its means. Indeed, it has taught us that sodium in one form or other exists almost everywhere. This mode of analysis is only serviceable to indicate the composition of any salt or other substance, the quantities of the different elements found by its use having no influence on the appearances brought out by the prism. Thus, a substance which has only been contaminated with sodium from being handled by warm fingers, will show the yellow bands as strongly as if it contained a large proportion of that metal.

For ordinary experiments in spectrum analysis the apparatus used is very simple. It consists of a tube with a fine slit at one end, and a convex lens at the other, for concentrating the light from the coloured flame upon the centre of the prism. After the light passes through the prism, it is examined by a small telescope of low magnifying power. The lamp used may be either a spirit-lamp or a colourless gas flame into which the substance to be examined is introduced upon a platinum wire.

We now come to another very important discovery, made by means of our prism and narrow slit—the determination of the composition of the photosphere or mass of luminous vapour surrounding the body of the sun.

A simple experiment will show how this brilliant discovery was arrived at. The light of a candle or other flame containing incandescent *solid* matter is passed through the spectroscope, and is found to decompose into a continuous spectrum, uninterrupted by dark lines. Between the light and the slit a spirit-lamp is placed, but no difference in the appearance of the spectrum is perceived. Introduce, however, the smallest portion of a soda salt into the non-luminous flame of the second-lamp, and a broad black line is immediately seen, crossing the middle of the yellow portion of the band of colour. Remove the sodium flame and the band disappears; but do the same with the lamp producing the spectrum, and the spectrum of course disappears, and the dark band caused by the sodium flame is changed to the yellow line produced by that metal. The same experiments may be tried with potassium, strontium, and other metals; and we shall always find that when a coloured flame is introduced between an incandescent solid and its continuous spectrum, it produces a series of black lines corresponding to the substances by which it is coloured. Thallium, in like manner, would give a black band in the middle of the green, and indium a similar one in the indigo. (Fig. 6, Frontispiece.)

The exact position of the black band in the middle of the yellow is shown in the coloured figure of the spectrum so beautifully printed in the frontispiece of this book, and it has been found to correspond exactly with the dark line D of the solar spectrum. The inference from this fact is obvious. The incandescent portion of the sun gives off light corresponding in its properties to that emitted by the solid matter contained in the candle flame, but the photosphere containing the vapour of sodium cuts off that portion corresponding to the sodium line. Accurate measurements prove that numberless other lines occurring in the solar spectrum are due to the vapours of other well known metals existing on the earth. Amongst these may be mentioned potassium, calcium (the base of lime), iron, nickel, chromium, and several others. This discovery with regard to the sun has resulted in the spectral examination of a large number of the fixed stars and nebulæ. For centuries the fixed stars refused to answer all questions put to them by mortals. The telescope showed them merely as bright points. Their nature and origin remained a beautiful mystery, until Dr. Miller, Mr. Huggins, Father Secchi, and a few other philosophers interrogated them in a manner that could not fail to draw forth an answer. They brought their light within range of their prisms, and forthwith they declared themselves to be suns like our own. It is true that before this they were looked on by most astronomers as bodies analogous to our own sun, but it was only reasoning from analogy, after all; but we are now able to assert with all the certainty that is compatible with human fallibility that many of these heavenly bodies are possessed of an incandescent centre, surrounded by a photosphere or envelope of gaseous matter in a luminous condition. It would be impossible to give a list of all the stars that have been examined up to the present time; the composition of the photospheres of a few must therefore suffice. It is singular that the elements hitherto discovered in the stars are those which are more or less abundant on the earth. Amongst them we may name hydrogen, nitrogen, sodium, magnesium, barium, iron, antimony, bismuth, tellurium, and mercury. The bright star in the constellation of Orion known as Betelgeux is one of the most singular in composition, the lines of its spectrum indicating the absence of hydrogen. If, as Messrs.

Huggins and Miller suggest, the worlds revolving round this star are also deficient in this element, they would be without water, like our moon.

Upon a very clear night it may be noticed that the stars are not all of the same colour, but that many of them appear to be of a ruddy or yellowish tint. The cause of this is plainly seen when they are submitted to spectral analysis. Thus, Sirius, which is a brilliant white star, shows but three dark lines, while one of the stars in the constellation of Hercules shows several groups of bands in the red, blue, and green portions of its spectrum, fully accounting for its orange tint.

The double star $\beta$ Cygni is a very beautiful example of the distribution of colour between two members of a stellar group. One star shows a strong spectrum with the blue and violet portions almost totally blotted out, while its companion is similarly circumstanced with respect to the yellow and orange portions of its spectrum. The colour of one is consequently orange, while the other is of a delicate blue. If these stars are the principal members of a system, the alternation of blue and orange days must be indeed a singular phenomenon to those who inhabit their planets.

In some of the stars lines have been discovered which do not possess any equivalent amongst those produced by terrestrial matter; they consequently contain elements of which we know nothing; at the same time, however, it has been found that terrestrial elements exist in some of the remote nebulæ, which are so distant that their light takes many thousands of years to reach our earth.

Spectrum analysis has decided the grand question of the physical composition of the nebulæ. Those bodies were supposed, with some reason, to be aggregations of stars, like our Milky Way, which only required telescopes of sufficient power to resolve them. That they partly consist of gaseous matter in a luminous condition is evidenced by their showing a series of bright lines in the spectroscope, exactly like those produced by terrestrial gases. Their light is therefore not emitted by a solid or liquid incandescent body, but by a glowing gas. The lines mentioned by Messrs. Huggins and Miller showed that the nebula in the sword-handle of Orion consists of hydrogen and nitrogen in a state of luminous incandescence. Not the slightest trace of a continuous spectrum can be detected in the light emanating from this body; consequently, according to present hypotheses, it contains no solid matter at all. A number of other nebulæ have given similar results.

There are numerous star clusters which, unlike the true nebulæ, give continuous spectra when their light is submitted to the action of the prism. Of these may be specially mentioned the great clusters in Andromeda and Hercules, which give continuous spectra, interrupted by dark bands on the red and orange. The light thrown by these experiments upon the nebular hypotheses of Sir William Herschel, who considered that true nebulæ consisted of the primordial gaseous matter out of which suns and stars have been elaborated, is very great, and will be appreciated even by those whose knowledge of astronomy is small.

Spectral analysis has also been the means of our witnessing a celestial conflagration, and understanding the cause of this marvellous event. It is well known to most people that from time to time stars have suddenly burst upon us, and have almost as suddenly disappeared. The theories advanced to account for these singular celestial visitors, have been more numerous than satisfactory. In May 1866, a star of the second magnitude suddenly burst forth in the Northern Crown, and was almost immediately noticed by Mr. Huggins who brought every power of prism and telescope to bear upon this extraordinary celestial phenomenon. He found the spectrum of the star to consist of two distinct spectra, one being formed by four bright lines, the other analogous to the spectra of the sun and stars. Consequently two kinds of light were given off by this star; one forming a series of bright lines indicative of luminous gas, the other consisting of a continuous spectrum, crossed by dark lines, showing the existence of a solid body in a state of incandescence, surrounded by a photosphere of luminous vapours. Two of the bright lines undoubtedly showed the presence of hydrogen in a state of illumination, the great brightness of the lines indicating that the burning gas was hotter than the photosphere. These facts taken in conjunction with the suddenness of the outburst in the star, and its immediate decline in brightness from the second down to the eighth magnitude in twelve days, suggest the startling speculation that the star had become suddenly wrapped in the flames of burning hydrogen, consequent possibly on some violent convulsion in the interior of the star having set free enormous quantities of this gas. As the free hydrogen became exhausted, the spectrum showing the bright lines gradually waned until the star decreased in brilliancy. It must not be forgotten that the event seen by Mr. Huggins occurred many years ago, and that the light emitted by this marvellous celestial convulsion has been travelling to us ever since.

Comets and meteors have been submitted to the test of spectral analysis. The former erratic visitors have been but few and small since stellar spectrum analysis has been perfected. In January 1866, Mr. Huggins brought his apparatus to bear upon a small comet, which gave a somewhat unexpected result. When the object was viewed in the spectroscope, two spectra were distinguishable—a very faint continuous spectrum of the tail, showing that it reflected solar light, and a bright space towards the centre of the spectrum, indicating that the nucleous was self-luminous and gaseous.

Mr. Alexander Herschel—the nephew and the grandson of Sir John and Sir William Herschel—has recently succeeded in obtaining indications of the composition of the meteors that people the heavens in the months of August and November. The principal result of his observations appears to be, that sodium in a state of luminous vapour is present in the trains left behind these singular bodies.

Lightning has also been similarly examined, and lines showing that hydrogen and nitrogen were rendered luminous during the electrical discharge, were seen with great distinctness. In fact, the applications of the prism to scientific discovery are almost endless, and in describing them it is difficult to tell where to draw the line.

Before quitting this subject, it will be as well to say a few words on the fluorescent rays of the spectrum, to which allusion has already been made towards the end of Chapter IV., Part II. It was there said that the chemical power of the spectrum extends to some distance beyond the extreme violet, a fact that may be readily proved by exposing a piece of photographic paper to the action of the dark portion of the spectrum. Professor Stokes found that there were means of rendering these rays visible to the eye by altering their rate of vibration. This he found was possible by passing them through the solutions of certain substances, such as sulphate of quinine, horse-chestnut bark, &c. We have already said, that light vibrating at the rate of from 458 to 727 billion times a second, was capable of exciting luminous sensations upon the optic nerve. The latter is the rate of vibration of the extreme violet ray, and it has been found that the eyes of many persons are not sufficiently sensitive to be influenced by it; it is, therefore, just probable that there are animals whose eyes are so much more sensitive than ours, that they can see rays that exist far beyond those seen by us. Now, as difference of colour is produced by difference in the rate of vibration, it follows that those whose eyes are sensitive enough to perceive the extreme violet rays, see tints of violet that are inappreciable by others.

The power of sulphate of quinine in reducing the luminous vibrations is easily seen by passing a tube filled with the solution successively through each of the colours of the spectrum formed by a quartz prism; the ordinary colours will pass through the liquid as if it were simply water, but on arriving near the violet extremity a gleam of pale blue light will shoot across the tube, and continue to increase. As it is moved onwards the light will gradually die away, until a point is reached nearly equal in length to the whole of the visible spectrum, when it will disappear altogether. It is somewhat singular that no substance has yet been found that will increase the refrangibility of the dark rays beyond the red end of the spectrum. There are many artificial flames which produce this dark light (if we may use such a paradoxical expression) in greater quantity than the sun, whose light is no doubt greatly deteriorated in this respect during its passage through the atmosphere. The substance of which the prism is made also greatly influences the length of the invisible portion of the spectrum. By using a quartz prism and lenses of the same material Professor Stokes, found that the spectrum of the electric light could be traced for a distance equal to six times that of the visible portion.

The action of certain substances in rendering the invisible rays of light perceptible may be easily shown by any one possessing a horse-chestnut tree. A weak decoction of the inner portion of the bark having been made and filtered through blotting-paper, or at any rate allowed to settle, the room is made quite dark and a piece of common brimstone is ignited. The pale blue light given off is comparatively feeble, but it is very rich in the ultra-violet rays; consequently, when the infusion of horse-chestnut bark is poured into a tall jar of water, beautiful waves of phosphorescent light are seen flashing backwards and forwards as the two liquids mingle. The tincture of stramonium is also possessed of this property, and characters traced on paper with it, although nearly invisible by ordinary daylight, appear distinctly when examined by the light of burning sulphur.

# CHAPTER X.

## SPECTRES—THE GHOST ILLUSION.

We close our account of the wonders of optics by a description of the ghost illusion, which has been exhibited with such great success by M. Robin, the well-known French conjurer, Mr. Pepper, the enterprising manager of the Royal Polytechnic Institution, and several others. Before doing so, however, we will say a few words on those unpleasant visitations known as spectres, to which some people are liable, either through an over-worked brain or some organic disease.

The peculiar appearances known as spectres in optics are certain illusions of vision in which an object is apparently presented to the view which does not really exist. In such cases either the brain, the retina, or the optic nerve are unnaturally excited, and made sensitive to an appearance that, physically speaking, does not exist. There is such a close connexion between the senses and the mind, that we continually, and without knowing it, transfer to the physical world that which belongs to the domain of thought. A picture which has struck us during the day will reappear to us at night during sleep, with every detail perfect, or possibly under a form modified by the capricious wanderings of our thoughts. A sudden fright may sometimes be the cause of optical illusions which will pursue us unceasingly. Fear, despair, passion, ambition, and other violent mental phases, are capable of evoking images closely connected with the state of our brain, appearances that we often take for realities, and whose truths we have to test by our faculty of reasoning, before we can set them down as positive illusions. "In the most insignificant phenomena," says Sir David Brewster, "we find that the retina is so powerfully influenced by exterior impressions as to retain the images of visible objects for a long time after they have passed out of sight; besides, this portion of the eye is so strongly influenced by local impressions of which we know neither the nature nor the origin, that we see the shapeless forms of coloured light moving about in the dark. In fact we have, in the cases of Newton and many others, examples of the ease with which the imagination revivifies the images of luminous objects for months or even years, after these impressions took place. After the occurrence of such phenomena, the mind can readily comprehend how thin is the division that separates reality from those spectral illusions which during a particular state of health have afflicted the most intelligent men, not merely those belonging to the community at large, but also the most learned philosophers."

Spectres may properly be divided into two classes, those which may be termed subjective, which result from some unnatural action of our minds or bodies, and which properly belong to the science of physiology, and those which may be called objective, which are caused by some peculiar illusion acting on us from without. We shall pass lightly over the first, illustrating them by a single example, while we shall pay more serious attention to those belonging to the second class.

Sir Walter Scott, in his *Letters on Demonology and Witchcraft*, mentions a remarkable instance of the first order of spectres. A doctor of eminence was called in to attend a gentleman who occupied a high place in a particular department connected with the administration of justice. Until the time that the physician's services became necessary, he had shown strong common sense and extraordinary firmness and integrity in every case in which he had been called upon to arbitrate. But after a certain epoch his temper became saddened, although his mind preserved its habitual strength and calmness. At the same time, the feebleness of his pulse, the loss of appetite, and impaired digestion seemed to point out to his medical adviser the existence of some serious source of disturbance. At first the sick man seemed inclined to keep the cause of the change in his health a profound secret; but his melancholy bearing, confused answers, and the badly disguised constraint with which he sharply replied to the interrogations of the doctor, caused the latter to seek for information as to the cause of the disorder in other directions. He made minute inquiries of the various members of his unhappy patient's family, but he could obtain no explanation of the mystery. Every one was lost in conjecture as to the reason of the alarming condition of the patient, which did not appear to be justified by any loss of fortune or beloved friends. His age rendered the idea of an unsuccessful love affair improbable, and his known integrity precluded the possibility of remorse. The doctor accordingly was compelled to return once more to the straight road, and he used the most serious arguments with his patient to induce him to conquer his obstinacy. At last the doctor's efforts took effect; the patient allowed himself to be convinced, and manifested his desire to open his mind frankly to the doctor. They were accordingly left alone, all the doors were securely fastened, and the patient made the following singular avowal.

"You cannot be more firmly convinced, my dear friend, than I am myself, that I am on the eve of death, crushed by the fatal malady which has dried up the sources of my life. You remember, without doubt, the disease of which the Duke of Olivarez died in Spain?"

"From the idea," replied the doctor, "that he was pursued by an apparition in whose existence he did not believe, and he died from the continual presence of this imaginary vision weighing down his strength, and breaking his heart."

"Well, my dear doctor," the patient went on, "I am in the same condition, and the presence of the vision that persecutes me is so painful and frightful, that my reason is totally helpless in controlling the effects of my imagination, and I feel that I am dying from the effects of an imaginary illness. My visions began two or three years since. At first I found myself embarrassed from time to time by the presence of a great cat, which appeared and disappeared I knew not how. But at last the truth flashed across my mind, and I was compelled to look upon the creature, not as an ordinary domestic animal, but as a vision which had its origin in some derangement of the organs of sight or in my imagination. I have no antipathy to cats, in fact I am rather fond of them, so I endured the presence of my imaginary companion so well that at last I treated the whole affair with indifference. But at the end of several months the cat disappeared, and was replaced by a spectre of greater importance, and whose exterior was, to say the least of it, very imposing. It was neither more nor less than one of the high officials of the House of Lords, in the full dress belonging to his dignity.

"This personage, who was in court dress, with a bag-wig on his head, and a sword by his side, his coat splendidly embroidered and his *chapeau bras* under his arm, glided along by my side like a shadow. Whether I was in my own house or elsewhere, he mounted the stairs before me, as if to announce my coming. Sometimes he seemed to mix with the company, although it was evident that no one remarked his presence, and I was the sole witness of the chimerical honours that this imaginary individual seemed to render to me. This phantasy of my brain did not make a very strong impression on me, although it made me conceive doubts as to the state of my health, and the effects it would produce upon my reason.

"This second phase of my malady, like the first, also came to an end. Some months after, the usher of the Upper House ceased showing himself, and he was replaced by an apparition that was at once wearing to the mind and terrible to the sight. It was a skeleton. Whether I was alone or in company this frightful image of death never quitted me; it dogged my footsteps and followed me everywhere, and seemed to be a shadow inseparable from myself. It was in vain that I repeated to myself a hundred times over that the vision was not real, and was only an illusion of my senses. The reasoning of philosophy and my religious principles, strong though they are, are powerless to triumph over the influence that besets me, and I feel that I shall die a victim to this cruel evil."

"It seems then," interrupted the doctor, "that this skeleton is always before your eyes?"

"It is my evil fate to see it continually before me."

"In which case it is at this moment visible to your eyes?"

"It is at present."

"And in what part of the room do you imagine that you see it now?" asked the doctor.

"At the foot of my bed," replied the patient: "when the curtains are half open I can see it place itself in the empty space between them."

"You say that you are convinced that it is only an illusion," replied the doctor; "have you the firmness to convince yourself of it positively? Have you the necessary

FIG. 72.—The Spectre. An optical illusion.

courage to get up and go and place yourself in the position which appears to be occupied by the spectre, in order to demonstrate to yourself positively that it is only a vision?"

The unfortunate man sighed and shook his head.

"Well," went on the doctor, "let us try another plan."

He quitted the chair on which he was sitting, at the head of his patient's bed, and placing himself between the half opened curtains, in the place where the patient had pointed out the skeleton, he asked if the apparition was still visible.

"Not the whole of it," answered the patient, "because you are standing between him and me; but I see his skull looking at me over your shoulder."

In spite of his philosophy, the learned physician could not help starting to hear that the spectre was immediately behind him. He had recourse to other questions, and tried endless remedies, but without success. The prostration of the patient, however, increased, and he died in the same distress of mind in which he had passed the last months of his life. This example is a sad proof of the power of the imagination over the life of the body even when the terrors endured are powerless in destroying the judgment of the unfortunate sufferer. We will say more; men who have the strongest nerves are not free from similar illusions.

The second kind of spectres, in which the science of optics plays so important a part, is the result of the imagination being deceived by art with the assistance of science.

These spectres are displayed in the ghost trick which has been practised at various Parisian theatres for a number of years, with very great success, more especially at the *Théâtres du Châtelet* and *Dejazet*. The Adelphi, in London, also employed Mr. Pepper to heighten the effect of the excellent acting of Mr. Toole and Mrs. Alfred Mellon, in the dramatic version of Dickens' "Haunted Man," by the introduction of various spectral effects. And the same trick was also called into requisition with some success in several of the minor theatres in New York and other cities of the United States. At the Polytechnic, in London, very remarkable effects were produced, and few who ever saw them will forget the surprise they felt at seeing the first representation of an imponderable ghost endowed with motion, and even speech. Amongst the most successful productions in this way was the entertainment of M. Robin, one of the cleverest of the many successors of the great Robert Houdin, the prince of prestidigitators. M. Robin claims to be the inventor of the ghost illusion, and to have shown it frequently since 1847. Whether this be so or not it is not our business to decide, but we can testify that his exhibition in the Boulevard du Temple drew all Paris to see it. Evening after evening he not only "called spirits from the vasty deep," but "made them come." He pierced them with swords, he fired pistols through them, and he made them appear and disappear at his slightest wish. He showed the Zouave at Inkermann, lying dead amongst a heap of slain, who at the familiar sound of the drum, rose, pale and grave, and showed the bleeding wounds from which he died. Amongst other scenes shown by M. Robin was one of a spectre appearing to an armed man, who after trying in vain to shut out the vision from his sight fires a pistol at the intruder. Fig. 72 shows the scene as seen by the audience, and fig. 73, the method by which the illusion is worked. The theatre is shown in section. On the left, at the end, are seen the spectators; on the right is the stage upon which the scene is represented. Beneath the stage is an actor clothed in white to personate a ghost, whose image is reflected by the glass above.

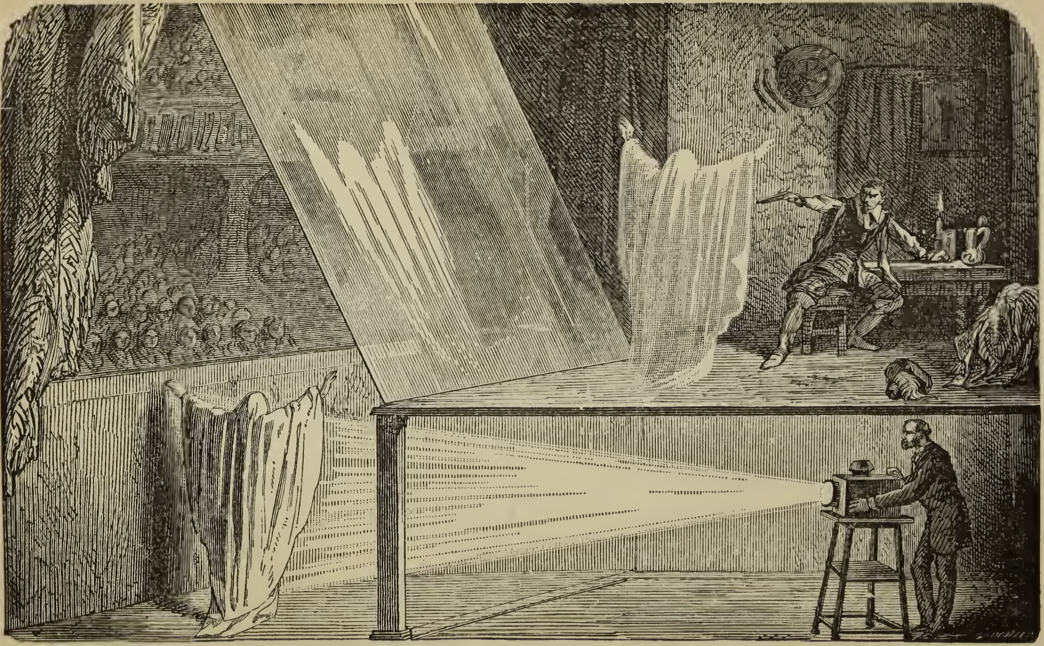


Fig. 73.—How to produce Spectres.

This glass is placed at an angle, and fills up the whole of the front of the stage, the edges being carefully concealed by curtains. The glass of course must be of a very large size, and should be of the very best quality, so that it cannot be seen by the audience. The actor must take care to place himself in such a position as to counteract the effect produced by the glass being placed at an angle. At first the cavalier is seen sitting at a table. After soliloquizing for a time in a very remorseful manner touching several murders that he has committed, the ghost of one of his victims gradually appears. This is effected by gently turning the electric light upon the concealed actor. The murderer and victim parley for a short time, when the former, being unable to withstand the reproaches of the ghost any longer, fires a pistol at him point-blank. The ball of course takes no effect, so the villain draws a sword, but before it has left its scabbard the spirit of the victim has vanished with a mocking laugh, or, in other words, the electric light is suddenly turned off. The management of the light is exceedingly difficult under these circumstances; the theatre, the stage, and the portion beneath ought to be lighted in a very careful manner, for if either is too bright or too dark it mars the whole effect. It must be remembered, too, that the person performing the part of the spectre and the real actor above cannot see each other, consequently all their action has to be carried on by guess-work. The actor below has to walk along an inclined plane, keeping himself exactly at right angles to it. Again, the movements of the latter are obliged to be reversed; for the cavalier already mentioned drew his sword with his left hand in order that the reflected figure should appear to use the right.

When well arranged, the ghost trick leaves far behind all the efforts of a similar nature that were obtained by the ancients in the way of magical illusions. It is also incontestably true, contrary to what some people have supposed, that they were unable to perform this illusion in the way we have described, for they were ignorant of the method of manufacturing and polishing glass plates of sufficient size and clearness for the purpose.

The production of living but impalpable spectres is thus a completely modern achievement, as we have already proved, and which has taken its place amongst the applications of science to stage art, to the total exclusion of all effects depending for their production on the old-fashioned phantasmagoria and magic lantern.

THE END.